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THE STORY OF THE EARTH

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VESUVIUS IN ERUPTION, 1872.

THE STORY OF THE EARTH IN PAST AGES

BY

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WITH FORTY ILLUSTRATIONS

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PREFACE.

I HAVE endeavoured to tell the story of the Earth so that its past history helps to explain its present condition.

Explanations are given of the nature of the common materials which form rocks, of the ways in which they rest upon each other, and of the means by which they may be distinguished.

The story of the Earth is divided into epochs by layers of rock which rest on each other and rise to the surface of the visible land, and to the floor of the ocean.

Geological time cannot be defined in years. The time occupied by an existing river like the Rhine or the Niagara river, in excavating the gorge through which it flows, dates back beyond the antiquity imagined for man by historians. Yet this incident in sculpture of the Earth's surface is subsequent to the newest of the regular layers of rock. It is convenient to forget the human standard of time, and think of a period of geological time as the age when some rock, such as coal, accumulated, or when an extinct plant or animal was dominant on the Earth.

Fossils are the remains of plants and animals by which each period of by-gone time is distinguished.

I. Many kinds of animals, which still live, date back to the beginning of the Earth's story, or to an early period.

II. Many groups of animals, such as Trilobites or Ichthyosaurs, endured on the Earth for long geological ages, varied in form and structure, and became extinct successively, leaving no survivor.

The life which now exists on the Earth is a survival of ancient types of life known from fossils, which have undergone substantially no change since first they became known in the rocks. They are associated now with groups, like the Mammalia, which are changing rapidly. The diversity of mammal orders in structure of the skeleton, is not unlike that which the ancient Saurians put on before they became extinct. Animals' orders which vary rapidly last for a relatively short time.

I have used some scientific names of these fossils in the story of the Earth, since names give the easiest identification for fossils as for our fellow-men. The characteristics or lives of fossil animals and of living men give interest to their names. Practical knowledge of fossils ensures this enduring interest, and is gained by collecting them in the sea-cliff, quarry, or pit, and by comparing such specimens with named examples in museums.

H. G. SEELEY.

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THE STORY OF THE EARTH.

CHAPTER I.

INTRODUCTION.

I.

THE building of the surface layers of the Earth is recorded in rock materials, which are accumulated upon each other. But there is no trace of a beginning to their story of the Earth's history. In the remotest period of past geological time of which evidence has been found, the earth was inhabited by types of animals, some of which still survive. There is no evidence that the most ancient animals which have been discovered were the first that existed, or that the oldest rocks at present known mark the beginning of geological records. It is as unprofitable to enquire for evidences of the origin of the earth, as it is to ask for proofs of the mode of origin of the life which has flourished upon it.

Because the earth is a planet we may assume that it had a similar history in its origin to some of the heavenly bodies. The light which comes to the earth from the most distant stars in the universe, proves, when analysed, to result from the incandescence of elements which are mostly identical with those found in the earth. The small masses of matter, termed meteorites, which fall from time to time to the earth's surface, con-

sist of iron and other metals, and of minerals like those which combine to form crystalline rocks. The forces which act on the earth are like those manifested in other heavenly bodies. If the Earth's surface is not incandescent, as in the luminous stars, its interior demonstrates in many ways an internal heat, which has played an important part in its history. So that, with the matter and force substantially the same, there is some justification for the old definition of geology as that department of astronomy which tells the story of the Earth.

The geological story differs from that told by the astronomer in giving results of unceasing action of the forces of nature upon the rock materials of the globe. They have worked during a time which is immeasurably long, when estimated by such changes on the earth as have happened during human history. This time cannot be expressed in centuries. The work of rivers in carving channels upon the existing surface of the earth has been computed at from 15,000 to 30,000 years, in the case of Niagara river, without reaching the age when the newer layers of the globe were deposited from the sea. This stupendous duration of time has brought about revolutions in the positions of oceans and continents; in the types of life which were predominant on the earth, as well as in the distribution of life over the globe, and in the succession of different kinds of life in the same region in successive ages, which would be incredible but for the evidence of fossil animals and existing animals which are everywhere around us. These changes have come about, not as result of catastrophes which have destroyed the fair surface of the land and its life, but as parts of the

order of nature, and as conditions of that stability of government of the world by which the creations of earlier times have been preserved, and passed on from one geological age to another to survive at the present day.

II.

On various parts of the globe, meteorites have been found which vary in weight from a few ounces to a few tons. Examples of 400 of them are preserved in the British Museum. Some have been seen to fall. It may therefore be inferred that ever since the earth has been in existence it has probably received such additions of material. Meteorites however do not demonstrate that the earth has been built up of meteoric matter; but they are the only clue of a practical kind to the origin of the globe, which the geologist encounters.

The iron in meteorites is metallic, usually combined with nickel. In the earth iron is rarely metallic, and rarely crystallized with nickel. Minute particles of metallic iron are present in the volcanic rock named Basalt, which has flowed over the north of Ireland. Iron is found combined with nickel in the Van mine in Denbighshire. The percentage of nickel in the iron varies in different localities. There is only one or two per cent. of nickel in the great masses of iron, sometimes weighing 50,000 lbs., embedded in Basalt at Ovifak in Disco Island, on the west of Greenland. An alloy of these metals found in New Zealand, yields 67 per cent. of nickel. Both are regarded as of terrestrial origin.

Although the mineral quartz is one of the most

abundant constituents of surface rocks, no true quartz has been recognised in any meteorite. But a rare mineral asmanite with many of the properties of quartz occurs, which somewhat resembles the variety of quartz found in some volcanic rocks, which has been distinguished under the name tridymite.

About ten rare minerals are met with in meteorites which have never been recognised in the rock materials of the globe.

On the other hand, earthy meteorites have yielded many of the constituents of volcanic and crystalline rocks.

Two kinds of felspar—named labradorite and anorthite—have been recorded in meteorites, and such minerals as Augite, Bronzite, Enstatite, Olivine, which upon the earth are often combined with the felspars in mineral union to form crystalline rocks. But the facts are too few and too obscure to do more than stimulate interest in the relation of the earth to the bodies among which it moves.

CHAPTER II.

THE EARTH'S INTERNAL HEAT.

THE earth has an internal heat of its own, which is not derived from the sun. The temperature of the outer surface layer varies with summer and winter. In Java and India at a depth of 12 feet the thermometer is constant all the year round. In London and Paris an unvarying temperature occurs at about 100 feet below the earth's surface. The earth's heat begins to increase be-

low this variable surface layer, though the rate of increase differs with the kinds of rock passed through, and with the locality. It averages one degree Fahrenheit for every 55 feet of depth.

In the famous Artesian well at Grenelle near Paris, the water rose from a depth of 1794 English feet, with a temperature of nearly 82° F. The deep boring at Sperenberg near Berlin appears to show an increase of 1° F. in 42 feet at the depth of 1000 feet; 1° F. in 57 feet, at 2000 feet; and 1° F. in 95 feet, at 3000 and 4000 feet. From these facts the inference has been made that temperature does not augment appreciably below a moderate external thickness of rock.

The difference between the surface temperature and the interior temperature, results from the loss of the earth's internal heat by radiation. On this circumstance attempts have been made to estimate the duration of geological time. By measuring the amount of heat which the earth radiates from its surface in a year, Lord Kelvin has concluded that in a period of 20,000 millions of years, more than enough heat would have been lost to melt the entire bulk of the earth, if the rate of loss had been always what it is now, and if the earth had consisted throughout of the same materials as its surface rocks. This is the time which the physicist conceives as possible for the earth's origin and history. Sir John Herschel had doubted the primitive fluidity of the earth. It is perhaps possible that the heat which the earth loses may not be the original heat of an igneous fusion, but the result of strain due to its rigid state. It rotates so that its surface experiences the lifting influence of tidal attraction which reduces the pressure, although the amount is too small to dis-

turb the stability of its surface. By the conversion of this attraction of gravitation upon its outer layers into heat, at a depth from the surface sufficient to ensure that the heat so generated could not be radiated in a day, a store of heat might accumulate near to the surface of the globe. The most ancient rocks give no evidence of greater internal heat, or of greater refrigeration of the earth, or of tidal action upon its surface having been in any way different from what it is now.

The greatest depth at which the fractures and dislocations, termed earthquakes, are known by actual measurement to originate, is about 30 miles. It has also been calculated that a heat sufficient to melt granite might occur at a depth of 20 or 30 miles. This is the maximum depth to which geological theory extends its inferences.

Attempts have been made to calculate the pressure under which masses of granite in mountain chains have consolidated. In some cases the crystal structure appears to indicate a superincumbent pressure equal to no more than 15 miles' thickness of rock, though the pressure was probably lateral.

The materials ejected from volcanos give no indication of having ascended from more than very moderate depths. The molten matter of lava streams does not appear to be the primitive substance of the earth's interior. That heated material might be rendered liquid by fractures which penetrate downward so as to remove the pressure which keeps the heated rock solid. It is thus manifest that some cause generates heat near to the earth's surface, which is associated with the crumpling of the earth's outer layers, with the changed distribution of level of land from age to

age, and with the phenomena of volcanic activity.

This cause is believed to be the cooling of the earth; by which the shrinkage of the deeper layers crushes the upper layers together, crumpling them into folds which are directed alternately upward and downward. As these folds are crushed closer together, the mechanical energy of compression, resisted by the rock material, becomes converted into heat along the lines of most intense squeezing.

The directions of these folds change from age to age in geological time; for every land consists of masses of rock which extend through it in directions which were once approximately parallel to its shores.

The late Mr. Robert Mallet believed that the energy of volcanic eruptions was developed by these compressions of the crust. He also urged that the lateral pressure exerted by the sides of an arch of continental land upon its supports would result in crushing along the lines of greatest weakness; and calculated that the temperature may be raised locally in this way to a red heat, or even to the fusing point of the rocky materials which are crushed. This heat, which is produced locally, he believed to be consumed locally, and to be the source of the explosive energy which ejects the materials of which volcanos are built up.

Active volcanos are commonly met with in regions undergoing upheaval. This is attributed to the underground compression of the rocks which causes upheaval, generating heat. The water near the shore which penetrates to the heated region is raised by that heat to an explosive temperature. Volcanos have a linear exten-

sion; sometimes in islands rising from the sea, sometimes in mountain chains formed of islands united together. The linear arrangement is attributed to the opening of fissures, which penetrate downward along lines, in which the rocks have been folded and fractured in the process of upheaval. When rain water, in a region so bent and strained, is held back upon the land and hindered from escaping by the pressure of the sea round its shores, the water descends through the minor joints and capillary interspaces between the particles of rock. Then it rises in temperature with the internal heat of the earth, so as to facilitate the melting of rocks, with which it combines. Some of this water eventually ascends through the planes of fracture and displacement forming outlets for explosive energy, discharging steam, dust, and the rock matter, both solid and molten, which builds volcanic cones.

The past periods of geological time abound in evidences of volcanic activity. From the imperfect nature of the records which remain upon the earth their linear arrangement is not always evident; but they may be inferred to mark lines of upheaval which brought islands into existence, or united them into continental masses of land in successive epochs of geological time. But besides the volcanos which are marked by beds of ashes and lava-flows, and the throats up which the molten matter ascended, there are in many parts of the world extinct volcanos with their cones well preserved, as though the craters had been recently active.

A little south of the Pyrenees, in the basin of the Ebro, there are fifteen cones about Olot in Catalonia, built of cinders, from each of which

lava has flowed in streams still to be traced, yet so long since that the existing rivers have cut passages for themselves through the lava.

The Auvergne is a granite platform in which some ancient rocks of the carboniferous period occur. This district appears to have been an island traversed by a line of fracture from N.W. to S.E., which corresponds to the uplifting of the crystalline rocks. A second fracture runs from N. to S. In this region are the ruins of the four grand volcanos known as Mont Dore, Cantal, Canton d'Aubrac, and Mezen. The lava flowed from Mont Dore for 20 miles. The minor cones, of which there are hundreds, range through the country in a broad band, from N. to S. Many have the craters burst down by the lava which ascended in them, and overflowed into the neighbouring valleys.

Beautifully preserved volcanic cones are found to the north of the Moselle river in the district known as the lower Eifel. It may have been in this country that the eruption took place which is mentioned by Tacitus as having affected the country near Cologne, in the reign of the Roman Emperor Nero. For a long way up the Rhine the rocks are volcanic; and evidences of extinct volcanos are found west of the Rhine, in many parts of central Germany; and a series ranges through Hungary S.W. of the Carpathians into Servia.

The latest volcanic outbursts in the British Isles were at the beginning of the Tertiary period in Skye, Rum, Mull and the adjacent mainland of Scotland, and in the north of Ireland, where streams of mud due to volcanic dust, washed down by rains, covered up the vegetation of the

country before it was deluged with the black lava named basalt. Branches of the conifer Sequoia, and of plane trees covered with leaves, are preserved in the consolidated mud which underlies these lava-flows.

CHAPTER III.

THE MATERIALS OF MOUNTAIN CHAINS.

THE same cause which produced the local heat and fractures which led to volcanic outbursts, has folded the earth's crust. Rocks many thousands of feet thick have been bent, folded and crumpled. This structure, which is shown in the succession of rocks on the surface of every country, in folds termed saddles and troughs, is most astounding in its intensity in mountain chains. The upheaving of the parallel ridges of limestone rock known as the Jura chain, forming the frontier between Switzerland and France, is a beautiful example of troughs which form valleys, parting the elevated ridges from each other. In that part of the Alps known as the Grisons, all the geological deposits, from the tertiary down to the oldest, have been turned upside down, in the process of folding by lateral displacement; which is the sole cause which lifts mountain ranges. The curved form of the earth necessitates that every axis of elevation must be accompanied by spurs at right angles to itself, or by parallel ranges. The parallel system is exemplified in the chains of North America, which lie between the Rocky Mountains and the Pacific.

These folds once formed remain for all time. They may be raised higher, or depressed beneath the sea, and new rocks laid down upon them; but as those ancient folds increase in intensity with the slow succession of geological ages, the newer rocks become folded with their folds, and the folds run in the same direction.

In such puckered and crumpled rocks as mountain chains exhibit on their denuded heights, there is almost invariably evidence of a crystalline texture. This may be attributed to the influence of the heat produced by the mechanical power, transformed by the resistance which the rock mass offered to compression.

The rocks which form mountains are chiefly slaty rocks, and schists, with here and there some granite masses or sheets of volcanic rock. They have only been laid bare by the removal of vast thicknesses of water-formed rock which once extended above them. If the crystalline materials are not the necessary products of the upward thrust of the mountain chain and adjacent land which supports it, it may be difficult to account for the uniform character of the rocks of which the durable central masses of mountain chains are built. There are stages in this process of change. The flanks of a mountain range commonly show the fine microscopic crystalline texture of slate, while the central masses show the coarse crystalline texture of schist, or granite.

Slate.—The part which slate plays in the formation of mountain masses is well seen in the structure of the mountainous regions of North and Central Wales, in parts of the Lake District in Westmoreland and Cumberland, and in the south of Scotland. It is certain that slate was originally

a water-formed rock, a mud which consolidated into clay. It often shows successive parallel beds marked by differences of colour. Welsh slates sometimes contain clay pebbles, such as occur at the present day on shores where the cliffs are of compact clay. Many slates contain fossil remains of animals which lived in the sea when the old mud was accumulating. Those fossils are often distorted and squeezed into half their original breadth or length, showing that the whole mountain mass has undergone compression and condensation. The compression has bent the rocks into synclinal troughs and anticlinal saddles. The slaty texture is most developed in the troughs.

The effect of this lateral pressure has been in the first place to turn the films of water contained between the particles of the old mud at right angles to the direction from which the pressure came. The resistance offered by the rock transformed a large part of the motion imparted to its particles into heat. That heat raised the temperature of the water contained in the rock, enabling each film, under the pressure, to dissolve some constituents of the mineral matter in which it was contained. These slaty rocks often give evidence of having been fractured through their thickness by minute dislocations, and subsequently re-united. Such breakage, relieving the pressure, would cause the temperature to fall, and the substances which had been dissolved then crystallize in minute films, parallel to each other, extending throughout the mountain mass, and having no relation to the original planes in which the mud was deposited. These microscopic crystal films resemble such minerals as mica or chlorite. They impart to the rock the property termed slaty cleavage. This

cleavage causes it to split in layers which cut across the original folded or faulted planes of bedding. This microscopic crystalline change of texture imparts to the rock, now termed slate, a remarkable durability. Its particles are laced together by a network of parallel films of microscopic crystals. Slates may be of any antiquity. Nothing but folding and uplifting of mountainous masses is needed to form them. In England and America they belong chiefly to the ancient epochs of time distinguished as pre-Cambrian, Cambrian, Silurian, and Devonian.

Schists.—The transitions between slate and schist are common in mountain regions. Crystals of other minerals are sometimes developed on the cleavage planes of slate. Some slates are very micaceous; and it is sometimes difficult to say where mica slate ends, and mica schist begins. The original bedding is usually obliterated in schists; so that the rocks give no evidence of having been deposited in water. Occasionally, as in the mica slates south of Bergen in Norway, beds of limestone, in which fossils are preserved, are found in such rocks. In the north of Scotland fossil-bearing beds, known as the Durness limestone, occur between schists, where they are introduced by horizontal dislocations.

A schist presents to the eye an arrangement of short irregular layers of crystals, which is similar to the appearance which a thin film of slate shows under the microscope, although schists differ from slates in having all their material crystalline. There is some reason for regarding them as results of intenser action of such compression as imparted a slaty texture to ancient beds of very varied mineral character.

A schist thus foliated is typically an alternation of films of the mineral quartz with some other minerals. Each quartz film is made up of a number of crystals matted together, and occasionally little plates of mica separate the individual crystals from each other. The mineral, which alter-

FIG. 1.—Gneiss: showing foliated structure, from Gairloch in Ross-shire.

nates with the quartz, gives its name to the schist, as mica schist, hornblende schist, chlorite schist. Some schists, such as gneiss, are identical with granite in mineral composition; some are identical with slates in chemical composition. Schists are frequently contorted and crumpled, as in the cliffs round Holyhead, with a minuteness of folding which is not seen in slates. Like slates they can be inferred to have been crystallized by the transformation into heat of the pressure which elevated them. They have been exposed at the surface by removal under the denuding action of water, of the rocks which originally covered them.

Schists often alternate with crystalline quartz-rock, which appears to have been originally sandstone, metamorphosed by partial solution and

crystallization which has blended the grains. In some localities, as on the west coast of Scotland, limestone occurs in schists and gneiss. Its texture is frequently compact and crystalline, and sometimes saccharoid like statuary marble. It contains many minerals but no fossils. All limestones were originally deposited from water. Thus the three chief types of water-formed rock —sandstone, clay and limestone—appear to be represented among schists. The process which has rendered them crystalline is termed metamorphism. Metamorphic rocks, which divide into layers by differences in the mineral character of their crystalline constituents, are said to be foliated. This foliation may be regarded as closely comparable with the cleavage of slates.

Schists may be formed of quartz, felspar and mica in parallel layers, when the rock is termed gneiss. The crystals of a schist may be thrown out of their parallelism, as in Anglesea, so as to present a confused mixture, which has been termed granite. Some observers, however, take the converse view, and believe that the original texture of the rock was granite, and that the schistose texture has been acquired by shearing movement acting on a heated plastic rock. In the south of Cornwall a schistose texture has been imparted in the metamorphic region of Cornish schists, to rocks which were originally volcanic.

Metamorphism is produced in several distinct ways. When the rocks of an elevated tract become changed in texture throughout their mass, the expression "regional metamorphism" has been used to distinguish such wide-spread transformations of rock texture, from the local altera-

tions of texture termed "contact metamorphism," which result from highly heated rocks acting upon the sediments over which or through which they flow. The changes produced by the action of the atmosphere and infiltrating water, which break up minerals originated by heat or pressure, and elaborate others in their place, give rise to "sub-aerial metamorphism."

In the central regions of mountain chains, such as the Grampians and the central axis of Devon and Cornwall, schists sometimes pass into the condition termed granite; so that there has sometimes seemed to be a relation of cause and effect between the position in which the granite occurs, and the way in which its mineral matter is arranged.

Granites vary so much in the minerals they include that they form a family of rocks distinguished by chemical and mineral composition and texture. The minerals depend upon the chemical constituents. The silica varies from 55 per cent. to 80 per cent. The alumina from 7 to 20 per cent. So that the quartz is commonly from a fifth to a third of the bulk of the granite, though occasionally nearly two-thirds. The mica may occasionally be only 1 per cent., though it is commonly between 5 and 25 per cent. The felspars form between 40 and 70 per cent. of the rock. Sometimes a green variety of hornblende gives rise to hornblendic granite. Granite may include angular fragments of schists, slate and limestone, often of immense size. These fragments appear to show that the granite is intrusive, and that it tore them away from rocks through which it passed. Instances have been recorded of granite resting upon schist. Granite

is also intruded on a smaller scale, forming veins, which penetrate into other rocks, or sometimes cut through the granite itself. The only evidence of the condition and temperature at which the granite was intruded is afforded by its junction with slate. In Cornwall, where the slate near to it has acquired the texture of mica schist and gneiss, there is no evidence to show whether that metamorphism was due to the heat of the granite, or to the pressure which it exerted, or both combined.

A few rocks which are found in mountain regions resemble granite in texture, but differ from it in mineral constituents, owing to the original chemical difference of the material out of which the crystals are formed. Syenite is well known in Charnwood Forest and in Guernsey. Syenite is a rock formed commonly of orthoclase felspar, hornblende and black mica. They are a variable group, including mica syenites, augite syenites, nepheline syenites, zircon syenites and many others.

A third type of granite rock is named gabbro. It is familiarly known in the Cuchullin hills in Skye. Its crystals are as large as those of granite, and similarly arranged. It is formed of a plagioclase felspar like labradorite, associated with some mineral of a brassy or metallic aspect like diallage, and often contains black mica and olivine; and in some localities hornblende.

These granitic rocks have been termed plutonic because they appear to originate in the region which mythology assigns to Pluto, in the interior of the earth, consolidating slowly under great pressure.

CHAPTER IV.

VOLCANIC ROCKS.

No clear distinction can be drawn between plutonic rocks and coarsely crystalline forms of volcanic rocks. Both are extruded in some instances from deep-seated parts of the earth. In consequence of the rigid condition of the globe it is impossible that those rocks came to the surface from an unconsolidated interior by ascending fissures. Many writers have assumed the existence of molten areas or lakes in the interior of the crust, as a source for lava streams, which sometimes flow on the surface for a hundred miles.

Others, again, assume that the longitudinal fissures, along which volcanic cones have been built, penetrate down to different layers of the earth, each distinguished by having the mineral character of the different kinds of volcanic rocks. Such a fissure allows the atmosphere to penetrate downwards, and removes from the heated rock the pressure which had kept it solid. The rock then liquefies and ascends the fissure like fluid in a pump, until it comes in contact with water derived from the earth's surface, and so generates steam, which forms the explosive outbursts. The steam ascends miles high into the air, carrying up the rock in the form of dust. The dust from the volcano Krakatoa, in the Strait of Sunda, ejected in 1884, remained suspended for more than a year.

On this hypothesis the difference between plutonic rocks and volcanic rocks is in the circum-

stance that the plutonic rocks consolidate deep in the earth, while the volcanic rocks consolidate under the pressure of the atmosphere, or near to the surface.

The principal types of volcanic rocks are named Rhyolites, Trachytes, Andesites and Basalts. The basalt has been supposed to be the last formed; and to have come from a greater depth than the others, being commonly the densest of the volcanic rocks. It frequently rests upon andesites and rhyolites. These rocks have been repeated several times in succession in the history of the earth. Rhyolites are found in the old pre-Cambrian rocks of Wales; andesites in the Cambrian rocks of the Lake district, and the Old Red Sandstone of Scotland; while in the later Coal Measures there were countless outbursts of basalt. The volcanic rocks of the Tertiary period in Britain are a repetition of those of the Primary period, basalts succeeding andesites and rhyolites.

There is at the present day something like a geographical distribution of the different volcanic rocks. The volcanos of the Andes pour out the rock named andesite. The volcanos of Southern Italy give out varieties of basalt. Metals are very rarely associated with volcanic eruptions, though an appreciable quantity of silver has been found in volcanic ash of eruptions in Chili.

Chemical and mineral composition alike suggest the closest relation between the deep-seated crystalline rocks and those which flow from volcanos. The plutonic granite appears to become the volcanic rhyolite. Plutonic syenite and diorite on reaching the surface appear to become andesite. And the rock which cooling under

pressure becomes gabbro, after flowing on the earth's surface becomes basalt.

Rhyolite.—The name rhyolite indicates the fluidal structure of the cooled lava, which results from the movement of minute crystals about larger crystals in the flow of the molten stream. Some of the crystals are visible to the eye. The material between them is named the ground mass. Under the microscope, this ground mass is seen to be formed of microscopic crystals, with an uncrystalline material between them, distinguished as the base. The visible crystals are principally quartz, with the glassy variety of orthoclase felspar named sanidine. These minerals may form the entire mass of a granite rhyolite. But rhyolite may be free from crystals, forming a glass, such as obsidian; or be expanded into a froth like pumice.

Nearly all crystalline rhyolites are full of concretions with a radiating structure, or alternations of granular layers with spherulitic layers, and these are known as spherulites. Besides the common form of quartz, another variety named tridymite occurs, in hexagonal plates. A little mica and sometimes hornblende may be diffused in the rock. The oldest British volcanic rocks of St. David's, Bangor and the Wrèkin, are rhyolites. Rhyolites and rhyolitic ashes often occur around granitic centres, as though they were mutually related.

Andesite.—Andesites contain 55 to 75 per cent. of silica. As the silica increases, the percentage of alumina decreases from 20 to about 12 per cent. The oxide of iron and lime also become less with the increase of silica. Typical andesites are formed of oligoclase felspar, and columnar

hornblende, in a glassy ground mass, with a little mica and magnetic iron. The quartz hornblende andesites correspond to syenites in chemical composition; just as syenites correspond chemically to some Cambrian slates. The hornblende andesites, which are free from quartz, are closely related to the rocks named diorites. Andesites are largely quarried on the Rhine, in the Siebengebirge, near the Apollinaris spring at Remagen. Andesite abounds in black concretions rich in hornblende, like those found in the granite of Shap in Westmoreland. Phonolite is probably a volcanic representative of a syenite which contains the mineral nepheline.

Basalt.—This is the most familiar volcanic rock. Its silica is reduced to 35 to 55 per cent. Oxide of iron, lime, and magnesia are more abundant in it than in other volcanic rocks. It consists chiefly of the minerals labrador-felspar, and augite, or some similar substance, usually associated with a little magnetite and olivine. It is dark in tint, grey-brown, blue-black, or greenish black when freshly broken. Cooled slowly, it gains a fine granular texture, and is known as dolerite.

In the most ancient basalts of Cambrian, Silurian and Devonian ages the olivine and augite have been partly decomposed, and converted into a green mineral like chlorite. The basalt or dolerite is then known as diabase. The less altered dolerites, of carboniferous age, have been termed melaphyres. Occasionally the felspar in basalt may be replaced by allied minerals. In Etna and Vesuvius leucite takes its place. There is also a nepheline basalt.

Olivine may take the place of felspar. That

mineral then gives a name, peridotite, to the rocks in which it is an essential constituent. Those rocks are frequently converted by decomposition into serpentines.

Volcanic rocks of the basalt family sometimes divide into beautifully regular six-sided columns, such as are familiar in the island of Staffa, and the Giant's Causeway in the north of Ireland. A lava flow sometimes cools from its floor and also from its upper surface; and two independent sets of vertical columns of different sizes may then be formed, separated by a crystalline part in the middle.

Each of these kinds of lava may also be represented by fragmental rocks, having the aspect of cinders, or dust. In past periods of geological time, beds of volcanic agglomerate, of ashes, and vesicular lavas are common in association with compact lavas. In North Wales, among the Arenig rocks, the ashes are enormously thick in Cader Idris, Aran Mowddwy and Arenig mountains, and there is little doubt that the ash was ejected from volcanic throats near Dolgelly and Arenig.

In the Permian rocks near Exeter, the beds of volcanic ash at Pocombe are manifestly drifted by the wind. And at Spence Combe the lava flow, is highly vesicular, with the vesicles filled with minerals, giving singular evidence of elongation of the steam cavities by flow in these old lavas of Devonshire.

There is a close chemical resemblance between the several types of volcanic and plutonic rocks, and a marked similarity in their mineral composition, which suggests a common origin. The evidence is not quite so complete that would tend to

establish a transition from the plutonic rocks through schists to water-formed deposits. It has not been fully collected, but deserves examination, since the earth offers no indication of a beginning in its geological history. If metamorphism such as is manifest in the older rocks were extended over the earth's surface it would obliterate records. And the wearing up of such metamorphosed rocks into new sediments would ensure a succession of similar rock materials.

CHAPTER V.

THE MATERIALS OF STRATA.

Terrestrial Rocks.

AROUND many parts of the coast, as in Lancashire and Norfolk, the winds blow up sands from the sea-bed, laid bare at low tide. These sands form low ranges of hills, known as sand dunes. They often show forms of hill contours as varied as are produced by the work of water and frost in carving hills out of solid material. These sand dunes are but an insignificant illustration of the work done by the wind, in heaping and rounding the grains of sand which form desert regions. There, every grain of quartz, which in a sandstone usually retains some of its angles of crystal form, is rounded by long continued motion, till it becomes a miniature pebble. There is some evidence that desert conditions not altogether dissimilar to those of Arabia or the Sahara may have existed in Great Britain at the beginning of the Secondary period of time, when the rock salt-

was in process of accumulation by the evaporation of land-locked basins of the sea. In Lancashire and Cheshire, in the lower part of the Trias, there are some layers known as the "millet seed beds" because the separate grains of sand flow between the fingers like millet seed or shot. Those minute pebbles are not all of quartz but partly of felspar. They can only be compared to blown sands of deserts in their pebble-like forms.

The less completely rounded sand grains in ordinary sandstones have probably acquired their character from long continued rolling, partly in rivers, partly on shores, as they have passed from one geological deposit to another in successive epochs of time, as a consequence of the construction of new layers of rock out of the materials of ancient lands; a process repeated again and again, and still in progress.

Another terrestrial rock which can scarcely be termed water-formed, because it is accumulated by vegetable growth, is seen in the peat, which covers large parts of the earth's surface where the mean temperature falls belows 42° F. It is well known that peat frequently originates in the fall of forest trees, because they obstruct the surface drainage on level lands, until bog plants grow and form a sponge-like covering to the land which buries the fallen trees, and kills the adjacent forest. Such accumulations in Cambridgeshire have been stated to attain a thickness of 40 feet. In the East of England, as in Ireland, there are two successive peats. The older has yew trees at the base; and the newer peat covers forests of pine trees. In the Fens of the Isle of Ely these peats are often separated by a clay of marine origin, the "buttery clay" of the Fen-man, the *Scrobicu-*

uãria clay of science, so named from a bivalve shell found in it, which lives in the swampy inlets on the east coast of England. In that clay are occasionally found the remains of walrus and seal, whale and grampus; showing that the inlet known as the Wash extended southward during the deposition of the clay, over the lower peat in much of the Isle of Ely. When peat becomes compressed by the deposition of superincumbent rock, it is consolidated like the rocks with which it alternates. There are important geological deposits, which have grown in the same way, in the successive periods of time. At the beginning of the tertiary period, at Bovey Tracey in Devonshire, alternations of lignite and clay form a succession of layers which fill up a lake-basin in the older rocks: similar growths are seen in the Bracklisham beds of the Isle of Wight. In the secondary rocks there is a remarkable bed of vegetable matter five feet thick, at Brora in Sutherland, which is worked for coal. Thinner beds are found on the Yorkshire coast, which appear to have grown like the modern beds of peat, in the positions in which they are found. Far more important are the beds of consolidated vegetable matter found in the upper carboniferous rocks of the primary period, which are commonly known as coal. They often give evidence of change in level of land during their accumulation; the same bed being thick in one place and divided up at a little distance by intervening sedimentary deposits. These accumulations of sediments preserve indications of the plant life of the earth, and in the associated sediments are occasionally found remains of insects and other terrestrial animals which lived in the same epochs of time.

Pebble Beds.

Any rock which is sufficiently durable to break into compact pieces may give rise to a pebble bed when the fragments are further reduced in dimensions by the action of frost, or the transporting movement of a flowing river, or the battering action of waves upon a shore or shoal. The harder rocks are not rounded into pebbles without long continued rolling. The term pebbles is applied to stones more than half an inch in diameter, so that they vary in size from Barcelona nuts to cocoanuts. Stones which are larger than these are termed boulders. Stones which are smaller are often termed grits. A river flowing two miles an hour transports stones as large as eggs, so that pebbles may be brought by such means from many kinds of rock which are exposed in the interior of a country. They are mixed and accumulated either on shores, or where the stream leaves them behind owing to its slower movement.

The pebble beds around shores are carried backwards and forwards with the daily movement of the tidal waters, and they serve to mark, when covered up by other sediments, ancient shores of seas which existed in bygone time. Pebbles which exist in the old geological deposits have been derived from granites and schists, from consolidated quartz rock, and lava streams, from consolidated sandstones, and veins of quartz which infiltrating waters have deposited in the cracks which upheaval has produced in ancient slates. Many beds of pebbles have been formed from concretions of flint, and similar substances, which

FIG. 2.—Conglomerate of flint-pebbles, from the Hertfordshire puddingstone, showing the external surface of the pebbles.

FIG. 3.—Fracture through this conglomerate, showing sections of flint-pebbles imbedded in a siliceous cement.

prove more durable than the geological deposits in which they were contained.

Pebble beds indicate the ceaseless action of water in wasting the earth's surface, which has gone on without intermission through all the periods of past time, because tides have never ceased to flow and ebb or rivers to run.

The positions in which pebble beds accumulate have changed, because the outlines of the seas alter with the folding of the rocks during past ages; and they frequently come back again age after age with variation in level of land, at long intervals to be re-deposited upon a shallow sea-bed, or shore-line in the same district.

Occasionally the pebbles are scratched, and some in the Permian rocks of Worcestershire are regarded as ice-worn fragments.

The pebbles are frequently bound together by a cement, which converts a loose aggregate of stones into a compact and durable rock. The most important of these cements is silica which is occasionally more durable than the pebbles which it binds together, as may be seen in the Hertfordshire puddingstone. Such rocks, named conglomerates, are also formed of pebbles bound together with a cement of oxide of iron, or of carbonate of lime.

Conglomerates and pebble beds are among the oldest known geological deposits in Britain. Among the primary rocks they are formed almost entirely of granite, schists, and lavas. Among the secondary rocks the pebbles which make up conglomerates are frequently derived from rocks that have more obviously had a water-formed origin. In the tertiary period of time most of the English pebble beds have been derived from the

grinding up of flints, liberated from the destruction of the chalk.

Pebble beds frequently mark important divisions of geological time in the country in which they are found; because their existence implies that change of level of land which resulted in the tidal denudation which brought them into existence. Among examples of great pebble beds and conglomerates may be mentioned the geological deposit known as the Llandovery beds, which in Wales forms the base of the true Silurian rocks, and extends successively over the upturned edges of the older Cambrian rocks, which had previously been planed level by the sea.

Sands.

There is a rapid gradation between pebble-beds and sands. Beds of intermediate texture, with many grains as large as peas, are named grits, and are typically seen in some layers of the "Millstone grit," which underlies the coal. The grains are miniature pebbles, often angular, formed by rounding angular masses of quartz rock on a sea shore. On a sandy shore, like that of Hastings, Reculvers or Hunstanton, the sands now being deposited are derived from sandstones which form the cliffs, broken up first by joints, and afterwards separated into grains, similar to the material out of which such sandstones were originally consolidated. Cambridge green sand and Neocomian sand contain many rock fragments and fossils derived from ancient deposits.

The particles of quartz are often crystalline, but are sometimes derived from uncrystalline forms of silica such as chalcedony, chert, opal,

and flint. Under the microscope the source of the grains can usually be recognised; for if the quartz was originally crystalline all the crystal faces are rarely lost, and the mineral may include hair-like crystals of other minerals, or minute cavities in which there may be fluid with a bubble of air. This is enough to show that the quartz came originally from the wearing away of schists or granitic rocks, in times when the level of the land caused those rocks to be exposed to the destroying influence of the waves. But although a sandstone is mainly formed of quartz, it rarely contains more than from 50 to 85 per cent. of silica—the whole of which is not in the crystalline form of quartz. There are frequently in a sand grains of water-worn felspar. The felspar, which is a silicate of alumina combined with a silicate of soda or potash, may decompose, liberating the soluble silicate of soda or potash. Felspar crystals abound in the old Cambrian sandstones of Barmouth, in the Devonian sandstones of South Devon, and in the Trias sandstones of the South of England. Sandstones often contain scales of the mineral mica, as in the Yorkshire sandstones, used for paving. Sometimes the mica decays, and then the iron oxide which was one of its constituents, gives a rusty colour to the sandstone. Many sandstones are mainly the grains of quartz, which were constituents of crystalline rocks, liberated by the decay of minerals with which they were associated, and left behind comparatively near to the source from which they were derived. The finer particles associated with them which resulted from the decomposition of other minerals have been carried to greater distances. A stream flowing three miles an hour at its bottom carries

away sand; but sand may be carried out to a distance of more than 50 miles from the shore. The

FIG. 4.—Laminated vertical sand (Bagshot sand) of Alum Bay in the Isle of Wight, showing current bedding.

size of the particles of sand when coarse is $\frac{1}{10}$ of an inch; but the majority of the grains vary from $\frac{1}{100}$ of an inch to $\frac{3}{1000}$ of an inch in diameter.

When a sand is laid down it is incoherent. It often shows evidence of its shallow-water origin, in the manner in which currents have brought its materials from different directions. After a deposit of sand is uplifted, and exposed to the action of rain-water flowing through it, it begins to be bound together by a cement which determines its

durability. There are three chief kinds of cement, which were originally of vegetable or animal origin. First, there is the iron sand which is commonly red, yellow, or brown; and is rarely green. The iron was probably collected from the sea-water by the growth of marine plants, and liberated by their decay. Oxide of iron is liable to accumulate in the planes in which water has flowed underground through the rock, which are sometimes determined by strain. Examples of sand so coloured are seen in the Bagshot beds of Alum Bay, in the Isle of Wight; and the Wealden beds of Warbarrow Bay, in the Isle of Purbeck. The Wealden sands of Kent and Sussex are so rich in iron that they were for a long time the main source of the metal out of which English implements of war and ornaments of art were made.

Sands are often bound into calcareous sandstones by a cement of carbonate of lime. It is sometimes derived originally from the evaporation of water, but more frequently from the falling to the bottom of organisms which lived in the water, or by the accumulation of marine shells. The Kentish Rag, which forms the lower part of the Lower Greensand, is a familiar example of a calcareous sandstone in the S. E. of England. The shells become dissolved by water flowing through the rock; and the carbonate of lime of which they consisted is re-deposited, so as to fill the interspaces between the grains of quartz, and form crystals which bind the sand into a sandstone.

The third kind of sandstone as modified by the cementing material is the siliceous sandstone, in which the grains of quartz are bound together by silica. These sandstones are of all geological ages. The material of the cement appears to be

in most cases, if not always, the minute particles of the siliceous skeletons of sponges, some of which resembled the *Euplectella speciosa* from eastern seas, sometimes known as Venus's flower

Fig. 5.—Ripple-marked sandstone from Permian Rocks in the Karoo, near Prince Albert, Cape Colony.

basket. The spiculæ which form the skeletons of such sponges, dissolved by the water draining through the rock, furnished a cement which is deposited in the same way as the cement of calcareous sandstones. Infiltration of this silica frequently builds, within the sandstone, compact layers of a flinty rock, known as chert. Such layers are found in the Lower Greensand, the Upper Greensand, and especially in the Carboniferous Limestone. In the S. E. of England the sands and sandstones, secondary and tertiary, are often coloured green, with the mineral glauconite. As a rule sands are red, yellow, or brown,

coloured with oxides of iron. They are shallow-water or shore deposits which show current bedding; due to deposition by changing currents, as well as ripple-marks of wave movement, and footprints of animals.

Clay.

Any substance which is taken up by moving water so as to cloud it, is popularly termed mud, and mud when deposited consolidates into clay. Mud banks abound on parts of the coast where clay forms the cliffs, because tidal movement of the water converts the clay into mud. It is chiefly composed of light flocculent particles of silicate of alumina, which frost tears apart from each other, and the lightest shower moves down a valley. The mud of rivers is carried into the sea, as far as the fresh water can float over the ocean. The Yellow Sea is yellow with the mud of the Hoang-Ho. When the Rhine at Bonn is turbid and full of water, $\frac{1}{5000}$ part of its weight is mud; but after continued dry weather the sediment falls to $\frac{1}{50000}$ part of the weight. Thus the alternation of seasons may give a laminated character to deposits carried to the sea, marking the succession of years by changes in the deposit, like the rings of growth in the wood of a tree.

When clay extends parallel to a shore, in consequence of denudation of the cliffs, it commonly has a definite relation to coarser sediments which are deposited nearer to land. This is seen in the large percentage of sand, sometimes amounting to 50 or 60 per cent., which may be separated from clays by washing. The particles of sand however are extremely fine, so that they are held in suspension for a long time by moving water.

Under such circumstances, the chemical composition of a clay is sometimes the same as that of a sandstone; and there may be an unbroken transition from one deposit to the other through an intervening loam. Almost all the minerals which enter into the composition of crystalline rocks, are occasionally found in clays. Often the origin of a clay is revealed in the abundance of the flakes of mica which are scattered through it, for the silicate of alumina corresponds chemically with decomposed felspar, and the presence of particles of quartz diffused in it, shows that the rock has been derived from an old crystalline material. The presence of mica renders it probable that the schists which were denuded were of the kind termed gneiss, if the crystalline rock was not granitic. Some ancient clays have been found full of needles of the mineral rutile. The purest clays are formed on land from the decomposition of white granite. Such a source would appear to be necessary for the beds of white pipe clay, found interstratified in the Bagshot sands of Hampshire and Dorset.

The colours of clay are due to oxides of iron. Occasionally, as in the Woolwich and Reading beds at Reading, current bedding is marked by alternate layers of red and green clay. Such bedding would be unsuspected, but for the colour. Often a blue clay passes into a brown or yellow tint. It is then sandy and porous, so as to permit the infiltration of water charged with atmospheric air, which oxidises the iron.

Minor sources for clay are the small percentage of silicate of alumina which is the insoluble residue left when limestones have been dissolved. This forms the red cave earth in limestone dis-

tricts; and the red soil on limestones. Beds of volcanic ash, exposed upon the surface, may become broken up by atmospheric decomposition and converted into clay.

The bedding of clays is frequently marked by the occurrence of thin layers of earthy limestone, or of concretions termed septaria, which are distributed in parallel layers, on zones where carbonate of lime was abundant. These concretions probably mark near approach to the limit to which the ancient mud was carried in the sea, where the sediment was becoming replaced on the ocean floor by calcareous layers of organic origin. The septaria often contain upwards of 50 per cent. of carbonate of lime, and their occurrence appears to mark, either oscillations in level of the sea bed which varied the distance to which sediment was carried, or indicates that the land area which was being worn away to form the new deposit became more calcareous.

One of the most interesting clay deposits in England is the inflammable clay, known as Kimeridge clay, found in Lincolnshire and Cambridgeshire as well as on the Dorset coast. Some layers of this clay when distilled yield as much as 40 per cent. of paraffin, naphtha, tar and heavy oils, which are similar to products of coal tar. Those chemical substances derived from coal being of vegetable origin, it is probable that the inflammable character of the clay is due to the growth of marine algæ, though no traces of plant remains are found among the remains of marine shells which crowd the deposit.

Almost all clays yield the minerals, iron pyrites, and selenite, which are closely dependent upon each other. Iron pyrites mineralizes fossils, and

occurs in irregular masses. Both iron and sulphur may have been liberated in the decay of marine plants. As the iron pyrites decomposes in contact with the air, its sulphur is converted into an acid, which dissolves the substance of shells, expelling the carbonic acid, and forming a hydrated sulphate of lime, known as selenite. Occasionally phosphate of lime form concretions in clays and mineralizes fossils. Clays are commonly formed in deeper water than sands, and further from the shores which furnished the sediment.

Limestone.

Limestones differ from other water-formed rocks in not being sediments. Their particles have grown, as portions of organisms; and have become rock substance, when the animals or plants died, which separated the carbonate of lime from water. Sometimes limestone is precipitated by evaporation of water. The carbonate of lime which forms limestones is usually in the mineral condition of calcite.

Beds of limestone may be deposited over the whole sea-bed, whether the water is shallow or deep. As a rule they are most noticeable in the open ocean, beyond the limits to which sediments are carried. Limestone may be formed near into shore; and when the rock is dissolved away by acids, in some cases nothing remains but a varying percentage of siliceous sand. Rocks of that kind are termed calcareous grits.

Evidences of the shallow-water origin of some oolitic limestones in the west of England, are also seen in current bedding, which characterizes some oolitic rocks, and is as marked as in sandstones.

The limestones named oolites, are probably all formed in moderate depth of water; since there is

Fig. 6.—Lithographic limestone from Solenhofen, showing circular staining at the intersection of rectangular joints; and corrugated fracture on the right side.

some evidence to show that the oolitic grains may be derived from plants like the Nullipores, and larger grains, termed Pisolite, show a minute tubular structure, attributed to an organism named Girvanella.

Beds of shell limestone are seen in process of formation on many shores. Shell-haven, in the Thames, takes its name from the manner in which shells are drifted together so as to form a deposit; and a similar accumulation may be ob-

served at Shell Ness which makes the eastern end of the Isle of Sheppey. Parts of the forest marble in Oxfordshire, consist of accumulated growths of shells; and in Gloucestershire portions of the same deposit show ripple marks which indicate shallow conditions of deposition.

Coral reefs are also to be classed as shallow-water limestones since the coral grows most vigorously where the water is aerated by the movement of the waves near to the surface of the sea. The

FIG. 7.—Carboniferous limestone, the surface dissolved by rain, showing the remains of Encrinite columns, of which it is partly formed.

great brainstone coral *Meandrina* and the compact coral *Porites*, associated with Nullipores build buttresses which constitute the living foundation of the reef. Our English coral limestones

all give evidence of shallow-water conditions, exactly such as are seen in the growths of fringing reefs of coral at the present day.

There is a second group of limestones which may be termed oceanic, or deep-sea limestones, made known by exploration of the floors of the great oceans. They are largely composed of the minute organisms termed foraminifera, such as cover so much of the Atlantic, Pacific and Indian oceans. Among geological deposits due to such organisms, may be placed the Chalk of Europe; the Nummulitic limestone, which extends through Europe, Africa, and Asia; and the Fusulina limestone, which extends from Russia to Japan.

There are other animals which appear to form deep-water limestones, since they live in some depth of water at the present day, such as the group of shells termed Brachiopoda; and Encrinites, which make up portions of the Carboniferous Limestone in this country.

An oceanic limestone is not necessarily built up in deep water, although such rocks often attain a great thickness. It is only necessary that the sea in which the rock accumulates should be beyond the limits to which sediments from land can be transported. Ocean basins often increase in depth as the deposit increases in thickness, when limestones may be formed as thick as are the Carboniferous limestone of Flint and Derbyshire.

Fresh Water Deposits.

Accumulations of sands, clays, and limestones are brought down from higher land wherever fresh waters accumulate upon the land surface If the pond or lake rests upon a limestone the

deposits formed within the lake will be mainly calcareous. Fresh-water plants like the *Chara* precipitate carbonate of lime upon the stem by absorbing the carbonic acid gas from the water, so that the carbonate of lime is no longer soluble. This ensures an accumulation of granular limestone as the plants decay. Such a deposit covers up the remains of fresh water shells, and frequently the remains of animals derived from land.

The lakes in Cumberland and Westmoreland are found to have their beds covered with deposits which consist of volcanic minerals when they lie in regions occupied by old volcanic rocks; while the deposits are ordinary sediments when the lakes are surrounded by rocks formed of such materials. If the lake is sufficiently large, like the Lake of Geneva, the sediments may be completely sorted, successively deposited, and pass from the condition of coarse pebbles and boulders where the Rhone coming from the Valais enters the lake, to the finest sediment where its clear waters leave it, southward of Geneva. Hence a lake may contain an epitome of all known water-formed rocks —pebble-beds, sands, clays, limestones—as well as layers of plant remains consolidated into lignite.

Examples of such fresh-water growth of sediments alternating with lignite, has been already referred to in the layers known as Coal Measures. In the lacustrine deposits which are so important in the northern part of the Isle of Wight, freshwater limestones are familiarly seen at Headon Hill and Bembridge, which were formed in freshwater lakes, and give no evidence of sediments being mixed with the calcareous matter. Other fresh-water limestones alternating with terrestrial

surfaces, on which the remains of coniferous forest trees stand erect, are seen in the Purbeck beds of the Isle of Portland and the Isle of Purbeck in Dorsetshire. Fresh-water sediments, alternations of sands and clays are found with numerous repetitions in the Wealden beds of the Isle of Purbeck, and the Isle of Wight; and they are associated into a few deposits, fairly well defined into sands and clays, in the Wealden strata of Kent and Sussex.

Recognition of the fresh-water origin of all such rocks rests upon the presence in them of animals which lived in fresh water. When these are shells they are often matted together to form layers of some thickness. The types or genera are identical with those which live in every pond, lake and stream on the surface of the country at the present day. The bivalve shells are usually species of *Cyclas*, or *Unio*, or *Anodonta*. The univalve shells are either the pond shells *Planorbis*, *Paludina* and *Limnæa*, or such river shells as *Neritina*, and the fresh-water limpet.

There is probably no fresh-water limestone from which the seed-vessels of the plant *Chara* are absent. Sometimes the presence of the siliceous spiculæ of the fresh-water sponge, *Spongilla*, has resulted in fossils being mineralized with silica, as in the Purbeck beds, or the formation of siliceous layers and concretions in fresh-water limestones, which may be compared to the veins and concretions of flint found in marine strata like the Chalk and Carboniferous Limestone.

CHAPTER VI.

THE SUCCESSION OF STRATA.

Contemporaneous origin of water-formed rocks.

THE conditions under which sediments gradually become finer, as the distance from shore and depth of water increase, show that all known varieties of rock may be formed and deposited adjacent to each other at the same time. Not only are the beds of peat in Irish bogs contemporaneous with the shell marls in the loughs, but these are contemporaneous with the sands, clays, and limestones which are forming at the present time in our seas. Any one type of mineral matter may be represented by all the other types of which layers of rock can be formed, in a succession of different localities. A geological period of time may be as accurately represented by terrestrial lignite, or fresh-water sands, as by any kind of marine deposit. The chalky muds dredged a few hundred miles west of Ireland are accumulated in deeper water in association with different types of life, but manifestly formed contemporaneously with the shell beds of Shell Ness, the muds carried out by the Thames, and the sands which are spread by the tides off Yarmouth.

In all geological ages there has been the same contemporaneity of rocks of different mineral character. Marine rocks must have been laid down at the same time as the fresh-water sands and clays of the Weald. An organic limestone like the chalk formed in the open ocean, necessitates shores where sediments were laid down.

And beyond those shores of the chalk sea were land surfaces of islands and continents on which plants and animals survived from age to age.

Lands have never ceased to exist from the earliest ages. They have changed their forms. Their height of elevation above the sea has been altered; they have been broken up into islands and re-united with other islands newly formed. The lands which exist at the present day are built up almost entirely of water-formed rocks, which have been spread out one upon another in the ocean. Every continent shows this history: a succession of ancient sea-beds, with the deposits formed upon them, alternating occasionally with old land surfaces which make known epochs when the sea-bed emerged from the ocean, and became land as it is now.

The shores, with their pebble beds and other evidences of tidal movement of the waters, have persisted from the earliest times, changing their positions upon the globe, as the lands altered their forms, never entirely passing away through the long epochs of geological time, although they only occasionally come back again to the places in which shores had previously existed.

The open ocean with its limestones has probably been equally persistent and as variable in form. Very little is known of limestones which may have existed in the earliest geological ages. But from their thickness and importance in the time named Devonian and Carboniferous, and in all subsequent times, it is inferred that the open ocean has persisted, though its depth has varied. There can have been no breaks in geological time, though there are breaks in the continuity of land surfaces, in the continuity of shore lines, and the

continuity of deposits of the open sea. These breaks are local, like the breaks which are made by the islands or lands which divide the sea, and by the waters which separate lands from each other.

The Succession of super-imposed Rocks.

A sediment may be followed round a shore line, so that it has everywhere the same general character, except in so far as the rocks of the cliffs vary, which give rise to pebble beds in some localities and scarcely any sandy particles on the shore in others. As a rule, tidal work sorts and sifts the products which the sea carries down to its depths, so that they are arranged in bands which are parallel to the coast. The particles vary in size in those zones of deposit. The finer particles remain suspended longest; and are therefore transported to the greatest distance by the moving water. Thus there is a horizontal succession of rocks on successive parts of the same ocean floor, which may be roughly classed as sands, clays, and limestones. Sands formed nearest to shore sometimes pass into grits and pebble-beds. And the limestones, like the sands, sometimes alternate with clays in vertical succession, where they pass horizontally into each other. Instances may occur where limestones extend continuously from the shore to the open ocean, without intervening deposits.

The horizontal sequence of water-formed rocks, observed at the present day, explains the meaning of the vertical succession of the layers of rock termed strata, which differ from each other in mineral character. By their superposition they build up most of the visible land, as well

as of those parts which are hidden under the oceans. Their vertical succession depends upon successive changes in position of the area from which sediments are brought into the sea.

If the land sinks down so that it becomes smaller, and its shores recede, each kind of sediment derived from it, being carried by the moving water the same distance as before its depression, is transported for a less distance out to sea as compared with the deposit formed previously. Therefore the finer sediments on a sinking sea-bed rest upon the coarser sediments, which had been formed previously, when the source of supply was nearer to the place of deposition. In other words, clays rest upon sands; while the new sands rest upon areas which had previously been dry land. If this process of depression continues, then while the clays follow the new sands, and become super-imposed upon them, limestones are super-imposed upon clays.

Sandstones occasionally give evidence that they were deposited between tide marks, in preserving the footprints of animals, as well as in the ripple marks, sun-cracks and rain-prints which were formed when the surfaces dried between successive tides. Such memorials are preserved in the Trias Sandstone of Cheshire, and the Hastings Sand. Clays occasionally, in the abundant remains of terrestrial plants which they yield, give evidence of estuarine origin, which may not be strictly comparable to the succession of conditions seen upon a land which is being submerged.

On the other hand some deposits are formed upon shores which are rising, and advance at the expense of the sea, and then the deposits which

result from waste of the land, succeed each other vertically in reverse order. In the sea which borders the coast of South America, the sand derived from its cliffs may be carried out to a distance of from 20 to 150 miles from the shore. The mud formed at the same time would be carried much further. If then such a land were to be enlarged by slow upheaval, so that the shore extended over the area which had previously been the shallow sea, two sediments which would still be formed would be carried as great a distance as they were carried previously, and the sand at its furthest limit from the shore would gradually extend beyond the limit of the sand beneath it, and would thus be super-imposed in part at least upon clay. In like manner the mud sediment would be carried further than the mud had gone previously, so that it would similarly rest upon limestone.

Therefore, under the influence of continual depression, the geological deposits come to be accumulated in the vertical order of sand, clay and limestone, in the same place. While under the influence of continued upheaval the vertical succession comes to be limestone, clay, sandstone.

There are constant oscillations of level of land which are evidenced by successions of sand and clay, or limestone and clay, which are local. And occasionally a sediment is derived simultaneously from two different sources, as when ancient cliffs furnish sand, and an ancient river supplies mud which is deposited at the same time, over part of the same area.

The layers of water-formed rock which form every land, succeed each other vertically in some such order as sand, clay limestone, limestone, clay

sand. Their order in Nature, as seen in the cliffs and on the surface of the land, is evidence of great upward and downward movements both of the floor of the ocean and the dry land, which have been brought about by foldings of the rocks.

Usually these rocks, the strata of sand clay and limestone, rest evenly upon each other, for the upward and downward movements are commonly so gradual, that while the rocks are distinguished from each other by mineral character, and the planes of bedding, which change with

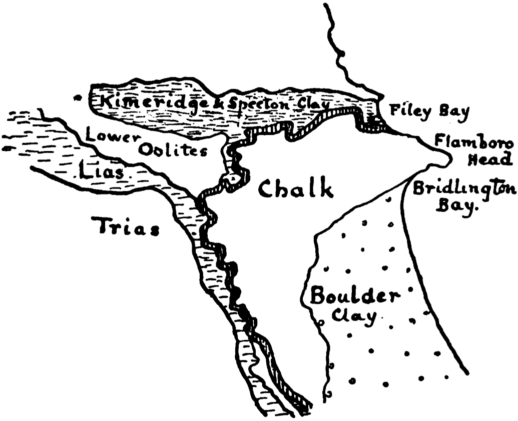


FIG. 8.—Geological map of part of Yorkshire, showing the westward extension from Flamboro' Head of the Chalk and Hunstanton Limestone, so as to rest unconformably upon the Kimeridge Clay, Lower Oolites and Lias.

depth of the sea-bed, there is no physical break in the succession of limestone on clay or clay on sand, and the beds in parallel planes of deposit,

are said to be *conformable* to each other. This is particularly true of an area undergoing depression. Yet as depression extends, and an area which had previously been dry land is submerged so as to be covered with new deposits, worn from the higher land which is near to the now submerged area, such a new layer begins a new order of succession in that district, and rests upon the edges of many older deposits which had been tilted up and worn level, so that their edges became exposed before the old land was raised from the sea. Such a succession is said to be *unconformable*. There is an unrepresented interval of time between such unconformable strata and the layers on which they rest; but the unconformity is local, and does not imply any real break in the succession of rocks, for the break is a consequence of the submergence of the denuded land, which had interrupted the even spread of sediments by the water, so long as it remained above the sea.

On the other hand, when land is undergoing upheaval, and the shore deposits begin to be raised out of the water, it must happen that the newest formed deposits will be worn up and removed before they emerge from the sea. There is a break formed in this way in the horizontal sequence, though there is no break in the vertical sequence of strata. Traced by their mineral character to the circumstances in which they originate, the whole succession of water-formed rocks which is known demonstrates no more than three or four great oscillations in level of the earth's surface, which have converted lands into seas, and seas into lands.

It is obvious that land is disturbed in level in

some localities, while the level elsewhere is unaffected, so that the succession of rocks may vary in mineral character in the disturbed district, with no indication of change in the succession elsewhere. On this account, the history of every part of the earth needs to be told separately from the other parts, for too little is yet known of the detailed events which took place in the successive periods of time, in the different portions of the globe, to piece the parts of the story together into a complete history of the earth.

CHAPTER VII.

ORIGIN OF STRATIGRAPHICAL GEOLOGY.

Geology originated in observation of the earth's surface, by which records were made of the order and arrangement in which different rocks occur in England and Wales. This knowledge is expressed in two laws. The first is the law of stratification. It affirms that the rocks which are anywhere exposed on the surface of the country are usually portions of layers, which rest successively upon each other. Therefore they rise from beneath each other, in the order of their relative antiquity, whenever they are inclined to the plane of the horizon. Every such layer is a stratum. Strata differ from each other in relative antiquity, in their mineral materials, thickness, extension, and degree of disturbance from the original condition of their horizontal deposition. The law of succession of the layers upon each other is named their *superposition*,

The second law is that every stratum may be identified by means of the included remains of plants and animals, termed fossils, which lived when its rock material was being accumulated in the part of the earth in which it is found. By these fossils the exposed edge of every stratum may be traced as it extends through the country. Therefore the area occupied upon the surface of the country by each geological deposit may be drawn upon a map. A map made in this way, which defines the limits of strata, lava flows, crystalline and other rocks which form the country, is a Geological map. It shows how the strata in a country may be distinguished and classified by the succession of groups of animals and plants which have followed each other in occupying the same portion of the Earth's surface.

These laws were discovered about 1790 by William Smith. He applied them in travelling through the country, so as to make the first Geological Map of England and Wales, which was completed in 1815. In 1816 his collection of fossils, which distinguish and identify the several British Strata, was placed in the British Museum. It became the foundation of the National Geological Collection and the beginning of all Geological Museums.

Other observers had recorded the order of the strata in different localities, and in some cases had recorded the occurrence of fossils in a single stratum; but without making the discovery that the strata may be identified by their organic remains.

Dr. Lister, in 1684, proposed to the Royal Society to make a map of the soils in our country. This was the first proposal to make a Geo-

logical Map. In one of his writings Dr. Lister gives a drawing of a small fossil, a Belemnite, and states correctly, that it is found in all the cliffs along the Yorkshire wolds, for a distance of more than 100 miles, by Speeton, Londesbro' and Caistor, but always in a red ferruginous earth [now known as the Hunstanton Limestone].

Mr. John Strachey in 1719 laid before the Royal Society evidence that the upturned and levelled edges of the Coal Strata in the Somersetshire Coal Basin were covered by nearly horizontal beds of the Red Marl, Lias, and Oolite.

The Rev. John Holloway in 1723 described to the Royal Society the parallelism of the Chalk of the Gog-Magog and Chiltern Hills, the Sand Hills of Woburn, and the Clay country drained by the Cam, Ouse, Nen, and Isis.

The Rev. John Mitchell in 1760 stated to the Royal Society that "we ought to meet with the same kinds of earths, stones and minerals appearing at the surface in long narrow strips, and lying parallel to the greatest rise of any long ridges of mountains, and in fact we find them [thus exposed]." The ridge in England which influences the direction of the strata is said to run first north to south, and then from north-east to south-west. Travelling between the Chalk hills of Cambridgeshire and the Coal of Nottingham and Yorkshire, he observed the succession of the strata; and in 1788, gave to Smeaton the Engineer, a table of these strata, with their thicknesses. They are enumerated in vertical sequence as Chalk, Golt, Sand of Bedfordshire, Northampton lime and Portland lime in several strata, Lyas, Sand of Newark, Red Clay of Tuxford, etc., Sherwood Forest pebbles and gravel

[fine white sand], Roche Abbey and Brotherton limes, Coal Strata of Yorkshire. This table was given to Henry Cavendish, who preserved it.

Mr. John Whitehurst in 1778 gave an account of the Geological structure of Derbyshire; and remarks: the strata follow each other in a regular succession, both as to thickness and quality, insomuch that by knowing the incumbent stratum, together with the arrangement thereof in any particular part of the earth, we come to a perfect knowledge of all the inferior beds, so far as they have been previously discovered in the adjacent country.

Smeaton in 1786 expressed his belief that the Lias extends from Watchet in Somersetshire to Barrow in Leicestershire, probably with few breaks in continuity, and through the vale of Belvoir into Nottinghamshire and Lincolnshire, beyond Grantham and Long Bennington.

There is no reason to believe that William Smith had heard of any of these observations. He was born 23rd March 1769, at Churchhill in Oxfordshire, upon the Oolites. He became a land surveyor and engineer; and at the age of twenty-one had found out for himself the succession of such rocks as he had seen, and had begun to compare the appearances at one locality with those observed at a distance. His work was distinguished from that of all predecessors by his method of untiring persistence in observing facts of stratification; activity in comparing, extending and establishing the conclusions to which those observations led; and care in recording upon his map nothing but what he had seen and proved. This work caused him to be known through the country as Strata Smith; recognised among geol-

ogists as the Father of Geology; and honoured as a great original discoverer in science.

CHAPTER VIII.

FOSSILS.

Geological and Zoological Aspects of Fossil Plants and Animals.

In the early days of geology fossils were regarded with interest because some species were limited in their range in time and only found in certain rocks. Attention was given chiefly to extinct species which were most abundant in each of the geological deposits. A large amount of practical work, in mapping the distribution of the strata, was done with the aid of very slight knowledge of a few species of animals.

It became possible also to group the rocks together in a rough way by limitation to the vertical range of a few fossils. The oldest rocks were defined as those containing Trilobites; the middle group as those containing Ammonites; and the newest group as containing Nummulites. The geologist, having to classify the rocks and identify them, was influenced in making divisions of the strata occur wherever a difference in life of any kind would permit the separation of strata, or groups of strata, from each other.

A dim idea prevailed that the change in life was in some way connected with the succession of geological periods of time. Hypotheses were put forward that the groups of strata correspond

to about six successive epochs, during which the life gradually became higher in the details of its organization. This theory was not suggested by examination of the rocks and their contents, because divisions which separate strata in Europe are differently placed in America. The hypothesis endeavoured to forestall results at which science might arrive. The species of fossils found in each stratum were supposed to have been created in the period of time when they were first met with; and to have become extinct when they disappeared with the succession of newer strata.

Naturalists found that existing life varies with elevation above the sea level, and that there is a relation between distribution in height and in horizontal area. While some of the plants found in Great Britain are identical with those of Germany, there are a few, living on high ground, which are Scandinavian types. In the south-west of Ireland there are a few Spanish and Portuguese types. The Scandinavian life was accounted for on the hypothesis that, in a recent period of geological time, those plants spread over land which is now the North Sea, when the temperature was lower than it is now. When the German types of plants subsequently spread over England, the Scandinavian species, which could endure greater cold, survived upon the hills; much as the Celtic population may have receded to the high ground before the invading Saxon peoples.

Considerations of this kind indicate two great laws. First, that the existing life which occupies the earth's surface is grouped in series of geographical assemblages, each of which may be termed a life province; and secondly, that these

provinces occupy changed areas of the earth's surface, with alterations in the level of land.

In the same way it was found that life in the sea varies with the depth of the water. Sea-shells which live between tide-marks, and are adapted to exist more or less exposed in atmospheric air, are different in genera or species to those in the deeper water, where the great growths of sea plants are found. Marine life again changes its character with greater depth. The shells which would be indicative of a shore, travel along the shore; and the shells which are found in clays, are rarely met with in sand. Marine life also varies geographically in the horizontal direction, because there are natural history provinces of life in the sea, which may also change their area, when the depth of water changes, so as to scatter or concentrate or combine the life.

About the year 1864 it began to be urged that the differences found in the fossil life between two successive geological deposits, were not due to great denudations of intervening strata, which had removed the intervening transitional organisms, making breaks in the geological record, but were the results of geographical migrations of organisms, so that these animals and plants came into an area which they had not previously occupied, by moving away from one which had formerly been their home. When fossilized, the remains of such a group indicate a different assemblage of animals or plants to those which lived previously in the area, when the life in the underlying stratum accumulated and was fossilized in the same way.

Thus it is intelligible that the distribution of life in the strata has been brought about in the

same way as the distribution of life is varied upon the earth's surface now. And instead of fossils in geological formations representing a multitude of successive creations, there appears to be but one creation. These types of life survived from the earliest time by undergoing more or less adaptation to altered conditions, as a necessary circumstance for their perpetuation through all the revolutions which the earth's surface has undergone.

Thus it is known that the elephant, hippopotamus, lion, hyæna, rhinoceros, which are now living in Africa, have been common animals in Europe and Britain since the time during which men have lived here; that those animals have changed their habitation; and that the area of the life province to which they belong is manifestly altered. There are no animals more distinctive of Africa at the present day than the hippopotamus and ostrich, but in a recent tertiary period of geological time, these animals left their remains in rocks of Northern India, in association with extinct allies of the giraffe, a type which is now limited to Africa. And so another change in the area occupied by a natural history province of life is made known by remains of animals preserved in the rocks.

All down the sequence of the geological ages the story is of the same kind. Wherever there is a change in the material of which rocks are formed there is a change in the distribution of life on the earth. The upheaval or depression which varies the distribution of the mineral matter and produces the succession of strata is also the cause which varies the distribution of life. Therefore the fossils found in any geological

formation are a portion of a natural history province, which has been preserved in the condition in which it existed on the earth's surface at that particular epoch of time.

If we suppose land and sea at the present day to be occupied over their areas with natural history provinces of life, in the manner in which they have been marked out by naturalists, such provinces are manifestly the survival of the life which has existed in the several periods of the geological record. They have reached their present positions in consequence of the geological circumstances of rock folding in the earth's crust which have given the earth's surface its present form. This truth is the only explanation of the succession of life in the past ages of the earth's history. It is impossible to imagine any change in life between the oldest deposit known and the bed which succeeded it, unless the life was already different in an adjacent area of the ocean, so that a new natural history province could be superimposed upon that which had previously occupied the ground. The fossils of the geological formations are therefore the records of the succession of the natural history provinces of life on the earth. Each province has been formed by geological changes. They have succeeded each other like the movements of chess-men upon the same square of the chess-board. In this process many of the old life provinces are broken up, and their constituent animals and plants scattered and intermixed with others, almost beyond recognition. Such survivals have not been accomplished, however, without the earth losing many of the kinds of life with which the geological story begins, and which characterize its greater epochs.

The Succession of Life.

The oldest geological deposits in the Cambrian period give no indication of a commencement of life on the earth. The assemblage of fossils, after eliminating the types which have become extinct, is comparable to such as might be found upon an existing sea-bed. The most ancient groups of fossils in the stratified rocks lend no support to the hypothesis that they are stages of a process by which animals came successively into existence, in the order of their grades of organisation. There are already several groups of animals co-existing, associated with each other as they are upon an existing sea-bed. On many shores at the present day the variety in life is not greater than the geologist finds in a quarry or cliff after examining a few yards of rock.

Each of the great divisions of the animal kingdom has representatives in very old rocks. Man is limited, so far as is at present known, to the newest deposits. But geological research has pushed further and further backward in time, the epoch in which each of the highest types—mammals, birds, reptiles, fishes—is first met with.

Sometimes the earlier rocks are fancifully spoken of as the age of fishes; those of the middle period are named the age of reptiles; and the latest rocks are termed the age of mammals. Each of those groups of animals puts on a considerable diversity of organisation in the epochs which it is supposed to characterize; and each includes some extinct groups which are not met with at the present day; or subsequent to the epoch which the group characterizes. On the other hand, mammals are not only not limited

to the tertiary strata, but have been recorded as extending to the Trias, the beginning of the secondary rocks. Indications of their existence occur in connection with each of the old land surfaces which the strata make known in the south of England. Birds have been found on two different horizons in the secondary rocks. The presence in those secondary rocks of animals so remarkable as Ichthyosaurs, Plesiosaurs, Ornithosaurs, Dinosaurs, and Anomodonts, fully justifies the term, age of reptiles. The modern type of crocodiles, lizards, turtles, and snakes, which are the true reptiles of the present time, do not extend back to very early parts of the secondary epoch, so far as is known at present. Extinct groups of reptiles such as the Anomodonts and Labyrinthodonts date back at least as far as the time in which the Permian and Carboniferous coal was accumulated. The great facts which life presents to us when examined by means of fossil remains, preserved in the succession of strata, are: *first*, that it has been always changing in the same locality, in the same way as a fauna or flora undergoes change at the present day. In the lifetime of individuals, plants and insects have disappeared from the fen district of Cambridgeshire under the influence of embanking and draining, just as in historic times animals like the wolf, brown bear, beaver and roebuck, have disappeared from South Britain. In other parts of the world the existing fauna has become poorer by the extinction of birds like the Dodo, and the Moa. This process of extinction has never ceased. Its evidences remain in the extinct species which characterize every geological deposit.

The process of extinction has extended to

some larger groups, such as in natural history are termed Orders of Animals. Thus in the old slaty rocks termed Cambrian and Silurian the entire group of animals termed Graptolites is extinct. In the primary rocks there is an extinct group of corals, termed Rugosa, which have the radiating shelly partitions termed septa, in multiples of four. There are small extinct groups of Echinoderms in the silurian and carboniferous rocks, allied to the sea urchins, named Cystoidea and Blastoidea. Among Crustacea there are the extinct groups Trilobites, comprising more than fifty genera; and the Merostomata, comprising animals which are allied to the king crabs and scorpions.

Other groups of animals, though not entirely extinct, are much better represented in the fossil state than in existing nature. Most of the genera of the groups of lamp-shells named Brachiopoda, are extinct, and found only in the Primary rocks; and the larger number of allies of the *Nautilus* are found in a fossil state, partly in the primary, and partly in the secondary period of time.

A number of the existing groups of animals date from very remote, if not from the earliest known geological ages. The genera in which they are first met with, frequently appear to have persisted ever since, without undergoing any appreciable change, beyond those minor modifications which distinguish species. Although the fruits of the *Araucaria*, of various pines, and of *Pandanus*, are found in the lower Secondary rocks, it is not until the latter part of the secondary period that any deposit yields enough fossil leaves to enable the vegetation of the earth to be compared as a group with living types. The common

genera of ferns of the present day are well represented in strata older than the chalk, by such types as *Pteris*, *Asplenium*, *Adiantum*, *Aspidium*, and *Gleichenia*. Palms are represented by Nipa. There are numerous representations of the oak, willow, beech, fig, laurel, ebony, magnolia. Nothing is known of the origin of this ancient cretaceous flora, but there is no ground for believing that it suddenly came into existence in widely separated parts of the world, where it is first met with.

In the oldest group of rocks every class of animals is represented by many genera which still live. Thus the Foraminifera, which fill so large a place in the life of the open ocean at the present day, are represented in the Silurian period by the genera *Dentalina*, *Lagena*, *Nodosaria*, *Textularia*.

The existing genera of Echinoderms are not known from so early a period; but in the beginning of the secondary time *Cidaris* and many other genera are found, which abound at the present day.

Among shells the Brachiopods *Lingula* and *Crania*, *Discina*, *Rhynconella*, *Terebratula* and others survive from the older primary time.

The common bivalve shells, which have few representatives in the Primary rocks, include such familiar forms as *Pecten*, *Pinna*, *Cardiun*, *Arca*, *Avicula*.

The common Univalve shells begin with such forms as *Patella*, *Pleurotomaria*, *Chiton*, *Natica*, *Trochus*, *Dentalium*, which have never since been absent from the earth. The *Nautilus* dates from a very early period.

Thus, although the history of life has left be-

hind enough extinct entombed forms to enable every deposit to be recognised by their remains, the great lesson of fossil remains is not so much extinction, as survival and persistence upon the earth of the life which has once existed. The natural inference would be that the variety in kinds of life has been steadily diminishing from the earliest time, owing to the loss of the extinct groups of plants and animals. But with each group of newer strata, genera and families of animals are met with among the fossils, which were not known in the older sets of fossils. There is perhaps no proof that they were previously absent from the earth; and it is possible that some of them may have come into existence as modifications of the types which were already in existence.

The variation which life undergoes as the condition of its existence.

There is a principle which affects the history of life, which necessitates that new modifications of plants and animals should constantly come into existence, under the varying conditions which the earth's surface assumes. The different organic types are saved from extinction by manifesting some degree of adaptation to altered circumstances. It is this property which enables the genus to survive from the earliest times. It undergoes a series of changes by which slight differences of form or ornament are perpetuated for a time, eventually giving place to another similar series of modifications; and these characters distinguish the species of which the genus consists. Even persons who are not trained to

recognise the technical characters by which animals and plants are classified, are aware that there are different kinds of scallop shells, and different kinds of cockles. The change in form and ornament can often be seen to originate as a consequence of the home of the shells being a place where the water is still, or one where it is exceptionally disturbed, the ribs of shells being always stronger in rough water. The presence of fresh water in an estuary would appear to be a frequent cause of variation, not only in ornament, but in form. Such variations of the common periwinkle and purple shell are found in Crag-beds at Norwich, and seen in inlets on the coast at the present day. Many of these variations are such as might characterize different genera if they were persistent and became permanent characters, but they do not even constitute species, and are only regarded as local races due to local causes. If it were possible that after a local race had come into existence, another set of circumstances affected it so as to cause variation to take place in some new direction, it may be that what was previously but a race character, would be perpetuated in all the new modifications, and become the distinctive attribute of a species, or even of a genus. The capacity of an animal for variation is usually in the development of something new, which did not previously exist; but the most remarkable evidences of variation are in the loss of parts which had existed in animals in a previous period of time. The capacity for variation is strikingly seen in the manner in which the antlers of a deer become complicated year by year, by the development of new processes. In the present state of knowledge

certain fossil deer appear to have had antlers which were less complicated; and in others the antlers were more complicated. It is on such characters that species of deer are distinguished.

All the higher forms of life which are distinguished in classification, are records of loss. Thus there can be no doubt that the common horse is closely related to the fossil horse named *Hipparion*, which had three toes on each foot, and the existing horse still preserves rudiments of the lateral toes which have been lost, in the splint bones, which occur at the sides of each cannon bone. Attempts have been made to show that the three-toed horse had ancestors with five toes, so that by loss of the digits of the feet, which are consequences of the ways in which the toes are used, genera may come into existence. At present there is very little in the way of fact out of which such a history could be constructed. Science can only be carried on, on a basis of unbroken evidence, from facts, which are to the scientific man what capital is to the merchant. There is, however, no doubt that the mammals have lost the composite structure of the lower jaw, which is found in reptiles; and that reptiles have lost the greater part of the arch of bones which in fishes intervenes between the brain case and the lower jaw, if their structures are inherited from one group to the other.

CHAPTER IX.

THE CLASSIFICATION OF WATER-FORMED ROCKS.

IN every country breaks exist in the continuity of the strata. Such interruptions in sequence are in progress at the present day by the upheaval of land of existing islands, and continents, which intermits the deposition of marine strata. Such breaks are evidenced by want of conformity in the order of succession of the deposits. This is one of the main grounds for dividing geological deposits from each other. The breaks which exist in any one country are somewhat limited in the area which they affect. They can never be world-wide divisions between strata. Strata are also divided according to their differences in predominant mineral character. The changes which take place in the prevalent types of extinct life which they severally preserve, give grounds for division of deposits, so that the cessation of an ancient group of animals, or the incoming of a new group, makes a division possible between the strata.

There is no necessary connection between the break in stratification, termed unconformity, and the break in life. Frequently there is a great change in fossils between two successive strata without an indication of unconformity. It is difficult to understand how the life can change appreciably without a change in the level of adjacent land, which causes the life of an adjacent area to migrate. An unconformity is not of necessity any greater evidence of an unrepresented interval of time than conformity; because

the unconformable beds might always be traced to a district where they become conformable, so that there is no break in the geological record.

The changes in life between conformable strata, are no more than the differences which zones of life assume with depth. As a pebble bed changes to a sandstone, its life alters from the fauna of the littoral zone between tide marks, to the fauna of the deeper laminarian zone. As the sand is succeeded by a clay the fauna alters to the life of the coralline zone. Therefore there is, from the point of view of the existing distribution of plants and animals, a necessary change of life, with change in stratification, which has no important connection with imperfections in the geological record.

The breaks in life and in stratification were stated by the late Sir Andrew Ramsay in the following series: Between the Lingula flags and the overlying Tremadoc slates there is a nearly complete break in genera and species; and unconformity is probable. There is the same condition between the Tremadoc slates and the Arenig rocks; and between the Bala and Caradoc beds below, and the lower Llandovery above. There is a great break in species in all these examples, and probably unconformity as well, but the unconformity is not seen. Between the Lower Llandovery and Upper Llandovery beds a break in life occurs, and marked unconformity; and between the Upper Llandovery beds and Wenlock beds, is similar evidence of a break in succession. The Old Red-sandstone however shows no sign of unconformity at the junction where it succeeds the Ludlow rocks at the top of the Silurian, and no break in life though both

might be expected. Nor does any break occur between the upper limit of the fresh water old red sandstone and the marine carboniferous rocks in the Welsh country. The carboniferous rocks are usually conformable from top to bottom; but there is sometimes an unconformable succession of Millstone grit upon mountain limestone, in the Forest of Dean. There is a great unconformity between the Carboniferous rocks and the Permian. This makes a total of ten physical breaks which are evidenced during the primary portion of geological time.

There is a complete stratigraphical break, or unconformity between the Trias and the Permian. Near Ormskirk the new Red Marl rests unconformably on the new Red Sandstone. There is no visible unconformity between the Rhætic beds and the Lias, which rests upon them, but the change in life indicates a great break in the uniformity of previous conditions. There is no complete unconformity between the Lias and the overlying Inferior Oolite. But the change in life to this deposit, and through all the succeeding divisions of the Oolites, is such as may be associated with unconformity in adjacent areas. At the top of the Oolites there is an insensible passage from the marine Portland limestone to the Purbeck beds. But since the Purbeck deposits include terrestrial surfaces, and are largely of fresh-water origin, an unconformity must exist in the south of England in this part of the succession. The wealden beds may also be unconformable. But in the overlying cretaceous series of deposits, the apparent unconformity is an overlap on the older strata which gave increased geographical extension to the Hunstanton lime-

stone and Chalk in the north, in Yorkshire; and to the Greensand and Chalk in the south-west of England.

There is no other physical break in this country till that between the chalk and the tertiary strata, which is partly bridged in Belgium, and perhaps entirely bridged over in North America. The upheaval of a succession of land surfaces in the tertiary period is evidence of remarkable breaks in the sequence of deposits, and then a great gap, unrepresented by strata in England, occurs in the middle tertiary period. The manifest physical breaks in the area in which the British strata were deposited, are much fewer than the breaks in the succession of life, many of which are evidently due to the way in which life is distributed in successive zones in depth. Therefore there has been no uniform principle in distinguishing the strata from each other by their fossils; and more attention has been paid to the differences in life, than to the circumstances by which the differences were caused.

In England the principal changes in marine life occur (1) between the Silurian and Devonian rocks, though the changes in types of life appear to be unimportant.

(2) Between the Primary and Secondary rocks there is a great change in both the marine and terrestrial life.

(3) Between the Oolites and Cretaceous rocks there is apparently an important change in the terrestrial life, though the change in the marine life is less marked.

(4) The gap in the marine succession between the Secondary and Tertiary is very striking; but the gap in the terrestrial plant life appears to be small.

It is on evidence of this kind that geological time is divided into stages, ages, and epochs, which record a series of transitions and successions, which the life of a limited part of the globe has undergone. Sometimes the diffusion of world-wide species appears to have been as remarkable in the seas of old geological periods, as any geographical extension of living species which is known at the present day.

CHAPTER X.

THE ARCHEAN ROCKS.

THE most ancient rocks are termed Archean. They consist chiefly of crystalline schists, and other crystalline substances, such as quartzite, limestone, graphite. Formerly they were generally regarded as metamorphic. At the present day some writers do not believe that they are crystallized out of ancient strata, which were accumulated in water. Nevertheless they show in many localities, and especially in the Laurentian rocks of Canada, two constituents which may indicate a stratified origin. One is the presence of layers of crystalline limestone, which is not known to originate in nature, except by metamorphism of limestone built up by organisms which lived in water. Secondly, these Laurentian rocks contain an amount of graphite, which has been stated to be equal in bulk, if it were all brought together, to the quantity of coal found in a coal-field. No source upon the earth for the carbon of which graphite consists is known, except the meta-

morphism of vegetable matter such as forms coal. Existing coal-fields show, in the formation of anthracite, what appears to be a transitional step between coal and graphite, for the percentage of carbon augments as the other gaseous constituents of coal are lost under the distilling action of pressure and heat.

If the Archean limestones and graphite are of organic origin, they would appear to have been originally beds of coal and limestone which consisted mainly, if not entirely, of fossils. Therefore, the other constituents of these rocks, the schists which form the great mass of the country north of the St. Lawrence, would appear once to have been sands and clays in which fossils may have been distributed as they are in more recent deposits.

The estimated thickness of the Laurentian and overlying Huronian rocks is about 50,000 feet, and in that thickness no fossil is found, unless the structure named *Eozoon canadense* which has been described from Laurentian limestones is correctly identified as an encrusting reef-building foraminifer; which its mode of occurrence in the rocks makes not improbable, though the structure is paralleled in volcanic rocks. Such metamorphism of ancient sediments all over the globe must be inferred to have obliterated all records of the early history of the earth.

The geological story commences at a comparatively late period, compared with the unrecorded epochs which have gone before. Without such an obliteration of a past record of almost infinite duration as compared with known geological time, it is inconceivable that processes of variation, such as are now known to be in opera-

tion, can have given rise to the diverse types of life, which the oldest fossiliferous rocks make known.

The Archean rocks are widely spread on the surface of Scandinavia, Finland and North-West Russia, Saxony, and Bohemia, and in Bavaria as well as in the British Islands. Rocks of this class will probably be found all over the globe, wherever there is an opportunity of examining the material upon which the most ancient fossiliferous rocks rest.

In the Western Highlands in Scotland, from Cape Wrath southward, the schists and fundamental gneiss of that region are displaced by an incredible multitude of horizontal thrusts which break them up into parallel sheets, almost as well marked as planes of stratification, with which they were at one time confused. Among these crystalline rocks are included great thicknesses of sandstones, and folded in among them occasionally are fossiliferous bands of limestone.

Other archæan areas are exposed further southward. The most interesting are the crystalline rocks about St. David's, in Pembrokeshire; at the Longmynd, in Shropshire; in the central axis in Carnarvonshire; and in Anglesey. In these most ancient British rocks, evidences appear to exist of contemporaneous activity of terrestrial volcanos, so that among the oldest British rocks, alternating with schists, are the rhyolite lavas of Bangor, Carnarvon, Llyn Padarn, associated in some of these localities with agglomerates. The Wrekin and Ercal Hill make known rhyolites of pre-Cambrian age which are associated with indurated volcanic ash. In the neighbourhood of St. David's the rhyolitic lavas

are in the same way associated with volcanic ash, interstratified in schists, the whole being affected by compression to which they have since been subjected.

The British Geological Record begins with conditions which indicate volcanic outbursts, and the shallow water accumulation of grits and pebble beds. As far as the evidence goes, similar conditions might exist at the present day; but the rocks have been modified from their original state by slow chemical changes.

CHAPTER XI.

CAMBRIAN AND ORDOVICIAN ROCKS.

THERE is an unconformity between the pre-Cambrian and Cambrian rocks, which implies a long interval of time, unrepresented by deposits in the localities which have been examined. The Cambrian rocks are of enormous thickness; and in Britain are probably not less than 30,000 feet thick in Wales and the border counties of England.

There is difference of opinion as to the use of the term Cambrian. Some writers make it include four groups of rocks, named Longmynd rocks, Menevian beds, Lingula flags, and Tremadoc slates. Others carry the name higher and make it include the succeeding rocks named Arenig, Llanvirn, Lower Bala and Middle Bala and Upper Bala, which have also been grouped as Ordovician.

The overlying strata, termed May Hill rocks,

the Denbighshire grits, Wenlock and Ludlow beds, and the Downton sandstone series, are combined to form the Silurian group.

From the physical history of the deposits, there is ground for dividing the rocks in this way, but from consideration of the life they contain, the whole might well be combined, and grouped together as ten successive series, with ten distinct fauna, which more or less resemble the life of similar natural history provinces, superimposed on each other, and preserved successively in sediments in the same area.

At first the old rocks which comprise the Longmynd groups, and the Harlech and Llanberis slates, which rise 1600 feet above the sea, in the Longmynd Hills in Shropshire, consist of slates, sandstones, grits, and conglomerates; with very few fossils. The water-worn pebbles in them prove deposition under ancient shore conditions; and they are associated with beds which show the ripples of waves, runnels of rills on the shore, interlacing cracks formed by the heat of the sun, prints of raindrops, and burrows of sea-worms closely allied to the living Arenicola. Few fossils have been found in the Longmynd. They are scarcely more numerous in the Bangor country of Carnarvonshire. There the rocks are represented by green and purple slates, which stretch from the banks of the Ogwen through the lake of Llanberis, and the Penrhyn slate quarries. In South Wales, in the section near St. David's, the interest of these rocks is greatest. The conglomerates and sandstones found there, with red, purple, and green slates, appear to be on the same geological horizon as the Bethesda and Llanberis slate quarries. Towards the base of this group

of rocks are found two genera of fossils named *Lingulella* and *Discina*, which may be regarded as having survived through all subsequent ages of geological time to the present day without undergoing any notable change, although the surviving shell is named *Lingula* instead of *Lingulella*. The lowest beds in which they occur, the Caerfai group, are succeeded by the Solva group, in which genera of the extinct order of Trilobites appear in profusion.

Here occurs the oldest known sponge named *Protospongia*, and a species is met with of the extinct genus of Pteropod named *Theca*, which survived in the ancient seas for a long time. This assemblage of life, the earliest as yet known in the earth's history, consists of types which are in no sense embryonic. It distinctly points to a line of similar ancestors which has yet to be discovered. With the succession of the overlying Menevian beds, and the succeeding divisions of the Lingula flags and Tremadoc slates, a fauna of 185 species of fossils becomes known in which

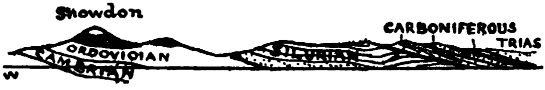


FIG. 9.—Section through North Wales from the Cambrian slates of the Snowdon district to the Cheshire Trias.

some of the shells, species of the genera of Brachiopoda named *Lingula* and *Orthis*, and *Obolella* pass up into the overlying Arenig rocks. With the Menevian beds the most ancient Echinoderm appears. It is a far-off relative of the existing stone-lines and sea-eggs. It belongs to the extinct group of Cystidea, and is named *Protocystites*.

The most ancient bivalve shells known are found in the Tremadoc rocks of Wales. They can be closely paralleled at the present day. *Modiolopsis* is probably nothing but *Modiola*, the horse mussel under another name; and *Glyptarca*, *Palæarca*, and *Ctenodonta* are only forms of the living genus *Arca*, in which the shell has not developed the habit of growing in depth along its hinge, as in most of its living representatives. Pteropods are well represented: the univalve Gasteropods are represented by the extinct genus *Bellerophon*, which appears to be a symmetrical shell abundant in the primary rocks, probably allied to the living *Pleurotomaria*. The group of many-chambered shells named Cephalopoda is represented by allies of the *Nautilus*, one of them the straight horn *Orthoceras*, and another *Cyrtoceras*, the curved horn. In the lower Tremadoc rocks the oldest known starfish is found, in a species of the genus *Palæasterina*; and the oldest known Crinoid or Stone-lily, in a species of the genus *Dendrocrinus*.

The great Arenig series rests conformably on the Tremadoc slates. It forms Cader Idris, the Festiniog Mountains, Aran and Arenig. It includes a great group of roofing slates worked in the quarries of Festiniog, and an immense quantity of volcanic ash. The total thickness of the ashes, agglomerates and lavas seen in Cader Idris is between 5000 and 6000 feet. The throats of the ancient volcanos which contributed so largely to form the Arenig rocks in North Wales, were placed near Dolgelly, and Aran Mowddwy by the late Sir A. Ramsay.

The Cambrian period was an epoch of vigorous volcanic action. The products of the volcanos are seen in the Skiddaw slates of the Lake

district, where about 12,000 feet of volcanic ash and Andesite lavas, of Honister Crag and Seathwaite, mark the beginning of volcanic action which continued through the accumulation of the Borrowdale series of rocks. In North Wales Rhyolitic lavas continued to be ejected in the Bala period which followed. They are seen about Bettws-y-coed and the Conway falls. Rhyolitic lavas are seen in the Glyders, on the north side of the Pass of Llanberis, near Bedd-Gelert, and about Snowdon.

The most remarkable feature in the life of these upper Cambrian rocks, is the extraordinary abundance of the extinct group of Graptolites. They are found not only in South Wales and the Lake District, but in as great a diversity of forms and complexity of branching structure in North America.

Trilobites increase in number of genera and species. The genus *Pleurotomaria*, a Gasteropod only known at the present day from living species in the West Indies and verging on extinction, appears for the first time in the lower Arenig rocks at Llanvirn, near St. Davids. In this period another Gasteropod *Euomphalus*, which continues to be important during the primary period, is found for the first time.

Several corals make their appearance in the Llandeilo rocks. They are the most ancient representatives of the group in Britain. Among them is the chain coral *Halysites*, and a species of *Favosites*, both of which are important genera in the primary rocks. The Crinoids increase in number.

Several genera of Brachiopod shells appear, two of which, *Rhynchonella* and *Crania*, afterwards

become much more important and still survive; while the genus Leptæna, which now first appears, lives on till the lower part of the secondary epoch of time. The common genus *Mytilus*, the edible mussel, is first found with the close of the Cambrian period. Cephalopods become more numerous and varied, and Cystidians are represented by a number of genera. The appearance and abundance of Graptolites, and the increase of Trilobites in number of genera and species, are the chief changes which occur in the life of the Cambrian period of time.

The Silurian.

The Silurian rocks extend unconformably over the Cambrian Strata. Between the Longmynd and Wenlock Edge, they cover up the whole series of the Cambrian strata, resting upon their upturned and denuded edges. But when they are traced into North Wales in Denbighshire, the evidence of Silurian unconformity is less marked.

The Silurian rocks typically include the Mayhill sandstone, the Wenlock rocks and the Ludlow rocks. The May Hill series, so named from May Hill in Gloucestershire, consists chiefly of sandstones and conglomerates, yellowish and brown with oxide of iron, about 1000 feet thick, covered by the Wenlock group, which in the south is formed of shales and limestones, and in Denbighshire chiefly of sandstones known as the Denbigh grits, which overlie the Tarannon shales. Above these rocks are the Ludlow beds, which also include shales parted by the Aymestry limestones. The Silurian group of rocks is capped by the

Downton sandstone, which makes a transition in rock character to the lower beds of the old red sandstone. These Wenlock and Ludlow rocks are the oldest British strata which include considerable beds of limestone. The exposure of Wenlock limestone at the surface forms the hill range south-west from Coalbrookdale, known as Wenlock Edge.

These beds indicate shallow-water conditions by the May Hill sandstones at their base. The shales, which are only hardened muds, were pre-

MAP OF AN INLIER.

FIG. 10.—Map showing a dome-shaped elevation of Silurian rocks exposed by denudation of the old red sandstone and carboniferous rocks which once extended continuously over the whole area.

sumably deposited further from shore; while the limestones, formed of corals, shells, and crinoids, were beyond the reach of sediment, but not necessarily formed in deep water.

The Wenlock limestone includes a large number of corals, and is the first indication met with in geological time of a British coral reef, though many of the beds are largely composed of Encrinites, and some of Brachiopod shells, showing the same conditions as are afterwards repeated

in the Carboniferous limestone, which is locally formed of many different organisms. There are twenty-five genera and seventy-six species of corals in the Wenlock rocks alone. And twenty new genera of crinoids appear, the group being represented by sixty-eight species in the Wenlock limestone. This limestone is frequently thin-bedded, and alternates with shale, often green, as is well seen in the dome-shaped exposure in the Wren's Nest, near Dudley, where it is covered by coal measures without any intervening rocks. The thin beds of limestone both in the Wenlock and Ludlow beds, thin out, first becoming nodular and concretionary, and then disappearing altogether.

In Wales and the adjacent parts of England the Wenlock rocks have been very little metamorphosed, and are in this respect in marked contrast to the cleaved slates of the Cambrian period. They have probably a wide distribution under the secondary strata, and were met with below the chalk and Gault at Ware, in a deep boring for water. The characteristic fossils are present. With the exception of the remarkable crinoids, corals, and brachiopods, there is nothing very impressive in the character of the Silurian fauna. The remarkable crustacea *Eurypterus*, *Pterygotus*, and *Hemiaspis* first appear in the Wenlock rocks.

The oldest fishes in Britain are met with in the Ludlow rocks, represented by no fewer than ten species. Among these is the Buckler-headed *Scaphaspis* in the Lower Ludlow, while in the Upper Ludlow are found *Cephalaspis*, afterwards known in the old red sandstone, together with *Pteraspis*, *Auchenaspis*, *Onchus*, and other genera.

The *Eurypterida* appear to have reached their maximum development in the Upper Ludlow period. There were probably more fishes living then than are yet known, since the Ludlow bone bed, which is found all round the Woolhope area, at May Hill, and in many other localities, consists largely of the remains of fishes matted together, with fragments of the great crustacea, some plants, and some shells. The Downton sandstones and Ledbury shales especially abound with the remains of *Eurypterus* and *Pterygotus*. With the Ludlow beds, trilobites become less important, and genera which occur in the uppermost Ludlow beds are also met with in the Devonian rocks. The wide-spread crustacean type, *Eurypterus*, is largely represented in Scotland. All the compound graptolites vanish, and the group disappears with a few simple species in the lower Ludlow beds. Ludlow rocks yield a considerable number of star-fishes, partly from Westmoreland, partly from Ludlow. Orthoceras is known from a multitude of species; and there are allied genera.

The organisms known in the lower Palæozoic rocks make up an enormous fauna, with multitudes of genera of sponges, corals, hydrozoa, crinoids, cystidians and star-fishes, trilobites, phyllopods, eurypterida, and every group of mollusca, as well as many fishes. It is in this period of time that the "sea-eggs," with flexible and elastic enveloping shells make their first appearance in British rocks, in the genus *Palæchinus*. They are of spheroidal form, and composed of numerous plates in rows which overlap each other obliquely at the edges. The group is always scantily represented in the geological deposits,

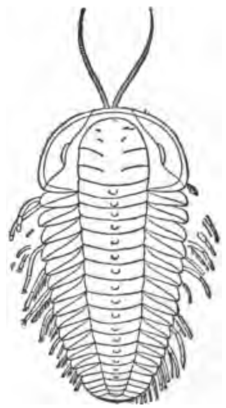
but still survives in the deep oceans, where it is represented by the genus *Calveria* dredged in 445 fathoms of water.

Trilobites.

Trilobites are a group of crustacea, entirely extinct, which appear in the oldest stratified rocks, and survive till the close of the carboniferous period. The group is characterised by having the body divided, first into a head-shield, termed the cephalo-thorax, which may theoretically consist of five segments of the immature animal, blended into one plate. In this shield, in a suture between the central part called the glabella and the free cheeks, the eyes are placed, when the eyes have a recognisable development. Some trilobites appear to be blind, being without eyes. On the under side of the head is the labrum, from which the long-jointed antennæ extend forward in a genus named *Triarthrus.* The middle part of the animal, known as the abdomen, consists of a number of separate overlapping plates, like those in the tail of a lobster, which are capable of moving freely upon each other, and are sometimes arranged so that the animal can roll into a ball, like the living terrestrial crustacean *Oniscus*, known as the woodlouse. The number of these joints in the abdomen, termed somites, varies from two in *Agnostus*, to about twenty in genera like *Paradoxides*, which is one of the oldest, and *Aulacopleura*, which is a Silurian type. Thirdly, there is a tail-plate, known as the pygidium, which is sometimes marked with external ornament, corresponding to that of the separate plates of the abdomen, and sometimes smooth. The eyes are

compound, and the individual facets can be seen with a lens, and although generally grouped together and raised in a crescent, as in the genus *Phacops*, appear sometimes to be scattered, so as to cover much of the lateral plates of the cephalothorax, as in the genus *Trinucleus*. The intestine is sometimes preserved. On the under side of the body numerous limbs were developed.

On the head, besides the antennæ, there were appendages for mastication, but only one of them is preserved. The jointed limbs on the trunk consist of two parts, one for locomotion, and the other a gill; so that they appear to belong to the leaf-footed group of crustacea termed Phyllopods, notwithstanding their remarkable external resemblance to the king crabs, towards which they approximate.



TRIARTHRUS.
FIG. 11.—A Trilobite showing feet and antennæ.

The limbs gradually diminish in size from front to back, where the hindermost are minute and rudimentary.

The two longitudinal grooves make the three lobes of a Trilobite.

The most ancient Trilobites include the simplest and some of the most complex. They vary chiefly in the number of segments; the form and size of the cephalo-thorax, and the pygidium; in the elongation of the pleuræ of the abdomen; in the external ornament of the carapace, which sometimes takes the form

of spines upon all parts of the body. As the Trilobite grows it is said to shed its shell like other crustacea; and with this growth there come to be additional plates added to the abdomen, so that there is a sense in which the ancient types, like *Paradoxides*, may be regarded as the most complex.

Among the Lower Cambrian genera are *Paradoxides*, *Dikelocephalus*, *Olenus*, *Conocoryphe*. In the middle and Upper Cambrian or Ordovician rocks, the common genera include Ogygia, Asaphus, Trinucleus, Lichas, Acidaspis. Phacops ranges through the Silurian and Devonian; and Illænus ranges from the Upper Cambrian to the Silurian.

In the Silurian, *Calymene*, *Encrinurus*, *Phacops*, and *Homalonotus* are characteristic genera.

In the Devonian rocks, Phacops, *Homalonotus* and *Bronteus* are commonest.

In the carboniferous, *Phillipsia* is the best-known genus.

CHAPTER XII.

OLD RED SANDSTONE AND DEVONIAN PERIOD.

A GREAT unconformity is inferred to divide the Silurian rocks below from the overlying strata. North of the Bristol Channel there is no evidence of marine origin for the deposits which appear to have been accumulated in great lakes upon a land surface. South of the Bristol Channel, and eastward through France and Germany, the rocks which follow upon the Silurian are entirely marine. They are remarkable for the

circumstance that the lowest beds exposed give evidence of shallow-water conditions in conglomerates and sandstones, seen in North Devon and West Somerset, in the beds known as the Foreland and Linton group. In South Devon the lowest beds are purple slaty rocks. The middle or Ilfracombe group, though mainly formed of slaty rocks, contains a little limestone.

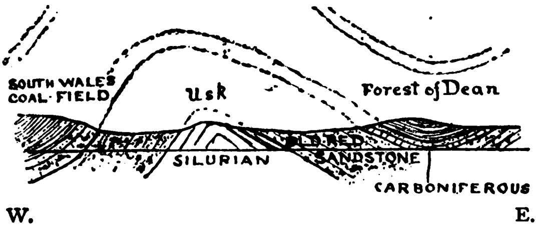


FIG. 12.—Section from west to east, showing how the Silurian, Old Red Sandstone, and Carboniferous rocks are folded between South Wales and Gloucestershire.

The limestone becomes more abundant in South Devon at Plymouth and Torquay, often taking the form of great coral reefs and sometimes thinning off into the shales. The uppermost Devonian known as the Pilton group in North Devon becomes sandstone. In Cornwall these rocks are represented by limestones and slates at Petherwyn.

The striking feature of these rocks is the remarkable change which takes place in the marine life. The multitude of genera which had survived more or less conspicuously from the Cambrian to the Silurian time becomes replaced by new sets of types which are substantially the same as survive through the marine beds of the

carboniferous period. Some layers are characterized by a few peculiar genera, such as the continental deposits in the Middle Devonian known from the Brachiopod *Stringocephalus*, as Stringocephalus limestone; and from the coral *Calceola* as Calceola slate, which give a distinctive character to the Devonian period. It is in the Devonian age that we are particularly impressed with the abundance on the earth of types of life which enter largely into the existing fauna.

Fishes have hitherto been few in number, but some of those remarkable fishes *Pterichthys* which occurred at the top of the Ludlow beds, together with *Coccosteus* and the great scaled fringe-finned *Holoptychius*, are found in the marine Devonian beds of the continent, as well as in the old red sandstone of Scotland.

In this period commence several marine univalve shells such as *Natica*, *Nerita*, *Trochus*, *Vermetus*, which are so important in the sea-shore life of the present day.

They are associated with two very interesting Cephalopods. *Nautilus* occurs accompanied by the remarkable Nautiloid shell named *Clymenia*, which has a fold in each septum which divides one chamber from another, similar to the fold which is observed in the septa of many tertiary species of Nautilus, which are similarly compressed from side to side. Those compressed tertiary species have the little tube named the siphuncle which passes through the septa placed in a more inward position than is usual in Nautilus. This genus *Clymenia* has the siphuncle as far inward as it could be, so as to be in contact with the previously formed coil. The genus is therefore in marked contrast to another remarka-

ble fossil named *Goniatites*, in which the septa are angularly folded several times, and the siphuncle is as far outward as it can be. Goniatites is the antecedent form of the great group of Cephalopod shells allied to *Ammonites*, which is found in the Secondary strata.

On turning landward to the lacustrine deposits of Old Red Sandstone age, the first of the great lakes in the British area on which the old red sandstone was deposited, is that which extends from Coalbrookdale southward over Hereford and Monmouth, and westward into Pembrokeshire. The sandstone accumulated in it is estimated to be about 8000 feet thick in Hereford and Brecon; and in Monmouth it includes thick conglomerates, full of quartz pebbles, which may be compared with those which formed the Millstone Grit, in a later period of time. The lower part of this area of the Old Red Sandstone is termed the cornstone group.

As might be expected there is an overlap of these beds upon the Upper Cambrian, which is well seen near Caermarthen.

Some of the marine fossils found in the Devonian of North Devon are also met with in Pembrokeshire. Hence there is some ground for believing that the old red sandstone, which is assumed to have been lacustrine, communicated with the sea by an estuary. This may account for the occurrence of some fishes indifferently in the marine and fresh-water beds, which are now separated approximately by the Bristol Channel.

All the other old red sandstone deposits are regarded as formed in lakes, chiefly in the lower old red sandstone period. These supposed lakes have been named from the geographical regions

which the rocks occupy. First, Lake Cheviot includes the Cheviot Hills with considerable thicknesses of volcanic rock of the kind named Porphyrite or Andesite. Further north a great lake, termed Lake Caledonia, appears to have extended southward from the Grampians over the Firth of Clyde into the North of Ireland. Third, the lake of Lorne covered part of Argyleshire from Loch Awe, and may have extended northward in the line of the great glen. Further north still is the old red sandstone region beyond the Grampians, which includes Caithness and Sutherland, the Orkneys and Shetlands. The lake is named Lake Orcadie. It is filled with conglomerates, red sandstone and grey flagstones, with occasional thin-bedded limestones, sometimes bituminous in the upper part.

In these beds there are many terrestrial plants, some coniferous, and some, such as *Lepidodendron* and *Calamites*, like those of the Coal, and similar to the plants found in the upper Devonian rocks of North Devon, probably derived from the land to the north. Pterygotus, which had appeared in the marine Silurian beds, is well known in the old red sandstone of Scotland, where it has been termed by quarrymen "fossil seraphim."

The fishes are of extreme interest. First, there is the remarkable extinct group of buckler-headed fishes represented by *Pterichthys* and *Cephalaspis*. Secondly, the more remarkable series of fringe-finned fishes termed Crossopterygidæ, which are represented at the present day by *Polypterus* of the river Nile. These fishes are covered with bony armour, and include a great number of types such as *Osteolepis*, *Holoptychius*, *Dipterus*.

These fishes do not appear to be in any sense

embryonic. They have great importance in the primary period. One of their living representatives, the *Ceratodus*, has, in addition to the gills which are common to most fishes, a lung which is adapted to breathing air under terrestrial conditions, as though it were possible for some fishes to have developed terrestrial habits of life.

Another interesting circumstance connected with the old red sandstone is the occurrence in it, in the Irish locality of Kiltorkan, and near Caerleon in Monmouth, of a shell, which has not been distinguished from the common pond mussel, named *Anodonta*.

Beds of the same age in Canada make known, among evidences of terrestrial life, large insects; and remarkable forms of myriapods, in which there is only one pair of legs developed on each segment of the body.

The accumulation of the enormous thicknesses of the old red sandstone deposits presupposes immense dimensions for a lake in which sediments three miles thick could be piled up, and a large area of denudation to furnish it with sediments.

CHAPTER XIII.

CARBONIFEROUS.

The carboniferous period of time has been so named because it is the principal geological epoch in Britain in which coal occurs. The rocks rest on the Old Red Sandstone in Scotland, and on the Devonian in the west of England. They are unconformable to the older rocks in some districts.

The carboniferous period, like the preceding epoch, gives evidence of conditions which are in part marine, and in part terrestrial. In the southern area, it is the marine condition which is chiefly developed in the lower part of the formation. Whereas, in the northern area, terrestrial conditions are developed towards the base. In travelling southward from Scotland over Britain the terrestrial beds come to hold a higher and higher position among the carboniferous strata. The formation is usually taken to include four or five chief divisions, which, commencing at the base, are reckoned as Lower Limestone Shales, Carboniferous Limestone, Yoredale beds, Millstone grit and Coal Measures.

The first point of interest of this epoch, is in the circumstance that in Scotland, the Calciferous Sandstone, which attains a thickness of 3,500 feet, lies at the base of the formation, so that the sandstone conditions of the carboniferous period, succeed to the sandstone conditions of the old red sandstone. There are occasional beds of limestone and shales, like the Burdiehouse limestone in the upper part of the group. The fossils include land plants. There is evidence of considerable volcanic activity, especially in the tuffs and andesite lavas associated with the calciferous period, in the Garlton Hills, north of Haddington. In the shales are one or two coal seams; and the shales themselves are sometimes so bituminous as to be a valuable source of mineral oil. The terrestrial conditions, which commenced in this way in Scotland, appear never to have entirely ceased in any of the areas in which the coal is found. There is therefore no great break in Scotland in conformity of physical conditions with the older

terrestrial and lacustrine conditions of the old red sandstone period. As the Calciferous Sandstone is followed southward, it becomes represented, first by the Tuedian beds of Northumberland and Durham, which are alternations of sandstones, shales and impure limestones. There is no Old Red Sandstone below the Carboniferous rocks in the North of England, and from the Cheviot lake to Coalbrookdale, the Old Red Sandstone is doubtfully represented. In the South Wales coal field, and the Bristol coal field, and the country of the Mendip Hills, the 400 or 500 feet of Lower Limestone Shale, with the bone bed at or about the base, consists chiefly of alternations of limestone and shale, more or less charged with fish remains. There is little to separate the marine life of this period from that of the Carboniferous Limestone.

The second division of the carboniferous rocks, known as the Carboniferous Limestone series, commences in the Scotch coal fields with sandstones, shales, fireclays, coal beds and a thin bedded limestone. The Scotch beds are grouped into the lower limestone series, the edge coal series, and the upper limestone series. The middle, or edge coal division, is about 600 feet thick; and includes among the sandstones and shales twenty-six seams of coal, now highly inclined, which grew where they are found, and each is more than one foot thick. The coal beds are not entirely absent from the upper limestone series, so that the representative of the Carboniferous Limestone in Scotland is important, as indicating terrestrial conditions which are not quite sharply marked off from those of the Calciferous Sandstone below.

Travelling southward a remarkable physical

change takes place. The carboniferous limestone consists of numerous alternations of limestones

FIG. 13.—Section showing the strata on the east of the Pennine chain.

with shales, which are well exposed in the dales of Yorkshire, where they are cut through by the rivers draining eastward into the North Sea. Above the limestone group, which is known as the Scar Limestone or Mountain Limestone, there is a superimposed series termed the Yoredale beds, which are well represented in Northumberland, Yorkshire and Lancashire, and are thickest on the west side of the Pennine chain. These beds are partly sandstone, termed Yoredale grit; but mainly shales, with impure limestone; so that they form, essentially, an upper division of the Carboniferous Limestone in the North of England. In Derbyshire and Flint the carboniferous limestone attains an immense thickness. And then southward, in the West of England and South Wales, it is reduced to 1000 or 2000 feet, with a capping of Upper Limestone Shale, which represents the Yoredale beds.

Where the limestone is well developed, whether in the west of Yorkshire or Derbyshire or Bristol, its organic origin is usually evident. It is formed in some places of the remains of Encrinites, in others of Corals, occasionally of Brachiopod shells, while there are a few localities, especially in the Bristol area, where the limestone is organic

in the same sense as the Oolites are organic, consisting of rounded grains cemented together which appear to have originated in the growth of marine Algæ allied to existing Nullipores.

Fossils of the Carboniferous Limestone.

The Carboniferous Limestone being in part a coralline limestone, includes a large number of corals. Probably the commonest genera found in Europe are *Amplexus*, *Cyathophyllum*, *Lithostrotion*, and *Zaphrentis*. They are numerous in species and abundant in individuals, and are all of extinct types.

FIG. 14.—Productus, a brachiopod of the carboniferous limestone.

The Echinodermata are largely represented; and propably in no deposit is there a greater number of crinoids. The principal genera are Actinocrinus, Cyathocrinus and Platycrinus.

The shells, however, are even more distinctive. The two genera *Productus* and *Spirifera* comprise more than half the species of Brachiopods. *Rhynchonella* is well represented in association with *Terebratula*. The latter two survive all subsequent revolutions of the earth.

Among the other shells, the bivalves *Pinna*, *Lima* and *Anomia*, *Avicula*, *Pecten* are associated with *Modiola*, *Mytilus*, *Arca*, *Solenopsis*, *Solemya*, types which appear to survive to the present day, more common on British coasts than in the carboniferous rocks.

Such univalve or Gasteropod shells as *Chiton*, *Littorina*, *Natica*, *Patella*, *Pleurotomaria*, *Turritella* and *Turbo* are surviving genera which are found in the Carboniferous Limestone. These are not always the genera richest in species. Aviculopecten, which is regarded as extinct, has more species than any other bivalve; and *Euomphalus*, also extinct, is one of the best represented genera of gasteropods.

Fishes abound, the cartilaginous fishes, or sharks, appear curiously to parallel both in their fin defences and teeth, the sharks which are subsequently found in the Secondary rocks. The ganoid fishes are also well represented. As a group they are unlike the types which lived in the old red sandstone time.

Millstone Grit.

This rock, mainly formed of quartz grains, is a shallow-water deposit, which often gives evidence of current bedding, and sometimes divides along planes in which the mineral mica is abundantly deposited. There is perhaps no good ground for separating these rocks from the overlying coal measures; and the sandstones which they contain are not more important than those known as the Pennant sandstones, in the coal measures of the West of England. They resemble the coal measures of the

FIG. 15.—Pleurotomaria, showing remains of the original colour bands on the shell. Carboniferous limestone.

south in the character of their sandstones and ironstones, and they yield, in various localities, some thin beds of coal.

In Scotland this third division of the carboniferous group of rocks, is named the Moor Rock. Its only difference from the Millstone Grit, is in containing marine fossils. But this condition probably only indicates that the lacustrine basins, in which much of the deposit may have been formed, were sometimes open to the sea. Southward in England, the Moor rock known as the Millstone grit, consists chiefly of alternations of sandstone and shale. It is only 50 feet thick in Leicestershire but thickens in the west. In Northumberland it is 400 feet thick. In the Forest of Dean it is less than 500 feet. It is 1000 feet thick in the Somersetshire coal field. From this deposit a large part of the flagstones of Britain is obtained. It forms the wildest scenery of the western side of the Pennine chain. This is due to the succession of the four principal beds of grit which rest upon each other in successive terraces, with the thick Kinderscout grit at the bottom, and the three less important grits above, which are all divided from each other by shales and sandstones. There are many thin beds of coal in the Millstone Grit. None of them are worth working, so that the coal miner knows the deposit in England as the Farewell rock, below which coal is not to be expected. The existence of the Millstone Grit indicates an upheaval of the Carboniferous Limestone sea, by which the conditions of physical geography became similar in England to what they were in Scotland. Such an upheaval exposed the uplifted rocks to denudation, and probably furnished the material

out of which the millstone grit sandstone was made.

The thick deposits in the south of England are near to the areas in which the thick masses of old red sandstone are found. It is possible that such a cause has governed the thickness of the deposit, though in the west of Pembrokeshire the Millstone Grit is only 300 feet thick; and it is difficult to see in areas now exposed any source for the Kinderscout grits, except in such ancient rocks of Shropshire as form the Longmynd, and the Denbighshire grits of North Wales. Denudation of the original materials from which such ancient rocks as those were derived would have made these sandstones.

The Coal Measures.

The rocks which yield coal are a succession of sandstones, and shale, ironstones, fire clays and coal seams, which are repeated over and over again. They thicken from Northumberland south-west to South Wales; chiefly owing to increase in quantity of the sand. In the north of England the thickness is 1500 feet; in the south-west in Wales it is 11,000 feet.

Fire clays are old soils of the carboniferous land in which the roots of forest trees often stand vertical, as they grew; showing that the coal was in most cases a peaty growth, like Irish bogs, due to the fall of forest trees, and the accumulation of vegetable matter where the forest trees had formerly grown. In South Wales scores of forest trees of the kinds named *Sigillaria* and *Lepidodendron* may sometimes be seen crushed flat like boards, piled one above another in the positions

in which they fell, before they became matted and compressed into a solid mass.

In some cases, the coal growth has been compared to the American swamps and cane-brakes, where the girdle of surrounding vegetation filters the muddy waters, so that only clear water reaches the vegetable matter in the enclosure. There is no doubt that carboniferous land surfaces were constantly undergoing depression of level, like the Deltas of rivers such as the Po, and the Mississippi, in many of which a succession of land surfaces has been found one below another, indicating accumulation of sediments which are similar to the coal shales and sandstones and resemble them, in the intercalation of vegetable growths between layers of mud. These depressions during the growth of the coal often appear to have been partial and local.

In the Dudley coal field the 10-yard seam is found, which is the thickest coal bed in England. When it is traced to the north, it subdivides into nine seams of coal, each having its own bed of under clay, on which successive forests grew. At Essington the nine beds preserve the thickness of the one bed at Dudley, though they have become separated from each other, by wedge shaped layers of sandstones and shales, which have an aggregate thickness of 420 feet.

The Dudley country is also interesting among English coal-fields on account of the volcanic eruption, which appears to have taken place during the carboniferous period; for the basalt at Rowley Regis, which was ejected through the coal, is in some places in the condition of cinder and ash; and this appears to prove that it was ejected at or near the surface. Volcanic out-

bursts are comparatively rare in the coal of England. In the Edinburgh coal-field the volcanic eruptions are the most impressive feature of the deposit. The layers of volcanic ash, and vesicular lavas, such as may be seen in Edinburgh, at Calton Hill, prove the outbursts to have been contemporaneous with the sediments. Regions of volcanic activity are commonly the scene of changes of level of land, such as the coal strata demonstrate.

The layers of coal may be compared to the growth of peat over the flat lands of Holland. The sea sometimes bursts in, as when the Zuyder Zee was formed, so that marine beds with marine shells, rest upon the terrestrial growth. Such catastrophes occurred in the Dudley coal-field, and more evidently in that of Coalbrook Dale. In the lower part of the coal measures is the layer of clay ironstone known as the Pennystone; and in the upper part is the layer known as the Chance Pennystone; both of these are marine deposits with marine fossils, like the shells *Goniatites* and *Aviculopecten*, which had not been seen since the Carboniferous Limestone was deposited. They were still existing not far away; but might have been thought extinct, but for these incursions of the sea.

There is no means of judging whether the coal or the intervening sediments occupied the longer time in forming. The total thickness of the coal in all the seams added together, varies from about 100 to 140 feet.

The properties of coal probably vary with the nature of the juices of the living plants. Thus, when starch is burnt it gives a vesicular coke or cinder. When gum arabic is burned, it forms a

hard dull coke like an imperfectly coking coal. When cellulose is burnt, it forms a coke which does not cohere, like the substance known as mother of coal. Hence differences which coals show in burning may depend upon the original substance of the plants.

The first important variety of coal Anthracite, which contains the largest percentage of carbon, is clean to touch, and burns with little smoke. In some localities anthracite appears to result from the distilling action of the heat which is generated underground by the folding of the rocks in a coal-field. This separates the mineral oil from the coal, so that the petroleum escapes into porous rocks like water, and may rise to the surface in springs.

Other coals are often termed bituminous, but no substance at all like bitumen exists in coal. Such coal is insoluble in any of the solvents which dissolve bitumen; but it softens at a low temperature. Caking coals partly melt, and make a compact coke.

The non-caking coal, like the steam coal of South Wales, does not change its form in burning. The properties of the coals vary with the different beds, suggesting differences in the species of plants which formed them.

The group of rocks termed Coal Measures is commonly divided into three parts. The lower coal measures, or Ganister beds, are usually barren, or only contain thin coals, which are not often valuable. Secondly, the middle coal measures contain most of the thick workable beds of coal. They correspond to the Pennant group of South Wales and the Bristol coal-fields. Thirdly, the upper coal measures yield a good deal of coal in

the South of England and Wales, but mostly in thin beds.

The coal was more widely spread in former geological ages than it is at the present time, though there is no reason to suppose that the vegetable growth ever extended continuously over the country. The several coal-fields are basin-shaped depressions, which have been isolated from each other, sometimes by denudation. First there has been the compression which elevated the Pennine chain and Wales. This divided the coal-fields into longitudinal series, stretching south on each side of the Pennine chain. Then the country was compressed in the opposite direction, forming folds which run from east to west. An upward thrust divides the coal-field of Northumberland and Durham from that of Yorkshire and Nottingham. Its effects are also seen in the separation of the Cumberland field from the South Lancashire coal-field. The folds which isolate the South Wales and Forest of Dean coal-fields and the Somerset coal-fields lie further south. Afterwards denudation removed the summits of the anticlinal folds, and the coal-fields remained in basin-shaped depressions.

Coal has been found by boring beneath newer rocks at Burford in Oxfordshire; and at Dover; so that these east to west folds of the primary strata beneath the newer rocks, probably extend continuous with the coal of Belgium.

Coal Plants.

About half-a-dozen terrestrial plants which are imperfectly known, have been described from rocks older than the Devonian. The flora of the

Devonian period does not differ essentially from that of the Carboniferous, since both contain the same genera of ferns, of giant reeds allied to the living *Equisetum*, and of club-mosses of the size of forest trees, which differ from the Quill-wort and *Lycopodiums*, more in size than in structure.

The Carboniferous period was an age of evergreen forest trees of types which did not survive the Permian period. No example is known of modern forest trees; but we cannot infer that they did not exist. The abundance of *Eucalyptus*, and of the leafless Acacias in South Australia shows how largely a few genera may monopolize the ground; and the circumstance that both the Australian and African floras are evergreen at the present day, proves that the absence of some types from a district of the Earth or deposit, is consistent with their existence at the same period of time in another locality.

Coniferous trees of the coal measures grew to a large size. In the forms of their fruits they resemble some of the yew tribe. The living *Salisburia* of China has fruits which are of nutlike form, and resemble the Coal Measure fruits known as *Trigonocarpon* which are produced by the forest tree named *Dadoxylon*. Under the microscope the wood of this tree shows characteristic coniferous structure. The tree differs from all conifers of newer age in having a large central pith, formed by a succession of thin transverse layers. Casts of the pith cavity were long supposed to be separate plants, and named *Sternbergia*. *Cordaites* is another conifer of the yew type. And *Araucarites* has been so named from its resemblance to the living Araucaria.

The club moss tribe, which at the present day

rarely grows erect, and never reaches a height of more than a foot or two, is represented by forest trees, which grew to a height of fifty to seventy

Fig. 16.—Part of the trunk of a Sigillaria from the coal near Huddersfield, showing the thin outer carbonaceous layer with leaf-scars.

feet. Like the conifers they have become known gradually, and each part of the tree received a distinct name, before the structure was known fully. In *Sigillaria* the trunk is vertically grooved, with the leaf scars extending round it in a spiral pattern. In *Lepidodendron* each leaf scar is enclosed in a lozenge-shaped area, and since these

areas are in contact, the spiral pattern is more marked than in *Sigillaria*. The roots of these trees bifurcate regularly at each subdivision, and the same structure is found in the branches which crown the trunk. The roots, formerly termed *Stigmaria*, have an irregular pitted pattern of scars to which long rootlets were attached. The fruits are cones, developed like clubs, at the ends of the branches. These fruits were termed Lepidostrobus. The existing *Lycopodium* resembles *Lepidodendron* in spiral arrangement of the leaves, fruiting organs and spores. The internal structure is essentially the same. *Lepidodendron* has a central pith, surrounded by woody tissue, which is formed of elongated vessels. Outside of that is the cambium layer of the bark, formed of large spherical cells, corresponding to the layer seen in the quillworts; and external to this is the bark, formed of small cells which are elongated.

FIG. 17.—Part of a frond of the fern Teniæopteris from the Indwe coal, Cape Colony.

Some of the layers of coal which are richest in hydrocarbons, such as the better bed-coal, are formed of spores of such plants. These spores

are usually large macrospores, such as are found in the lower part of the fruit of the living *Selaginella;* and the fossil *Triplosporites.* The fossil reeds of the coal, termed *Calamites*, are closely related to the living *Equisetum*, although the plants grow to a comparatively large size. Externally the plant terminates downward in a cone. The trunk is divided transversely by nodes, and the internal cast of the internodes is fluted. At the nodes the stem gives off leaves in circles, and these leaves supported leaflets arranged in whorls. The leaves are known as *Asterophylites*, with needle-shaped leaflets; *Annularia*, with blade-shaped leaflets; and *Sphenophyllum*, with wider wedge-shaped leaflets. There are also several types of fruit, which closely resemble the fruit of Equisetum, except that some of the leaves do not bear sporangia, and thus form a protective covering to the others. The spores are of the same size in the living and fossil types.

The ferns of the coal known under such names as *Alethopteris*, *Neuropteris*, *Odontopteris*, *Sphenopteris*, closely resemble existing ferns, in so far as can be determined; for the fructification is not often preserved. Four of the eight existing families of ferns are known in the coal measures. Tree ferns have been described.

Animals of the Coal Forests.

Terrestrial shells are not preserved in many geological deposits, and only two genera are known from the Coal Measures. They are both small, and were found in a bed of underclay, in a layer about two inches thick, in Nova Scotia, probably swept down by the rain, as shells in a

forest often are at the present day. One of these shells is a thin variety of the common hedge shell of Great Britain, named *Helix*. The second appears to be identical with the existing genus *Pupa*, which is commonly found about the roots of trees. They are the oldest terrestrial shells known.

Associated with the land shells are centipedes. The group of Myriapods to which they belong is distinguished by having one pair of antennæ, eyes nearly always simple, no distinct thorax, and no wings; while limbs are attached to nearly all the segments. Like insects they have three pairs of jaws. The respiration, as in insects, is carried on by tracheæ, which open near the articulations of the legs, except in the living genus *Peripatus*. Myriapods live in the loose bark of trees, in cracks in the rock, and under stones. The oldest forms were found in the hollow trunks of *Sigillaria*. They are Millipedes rather than centipedes. They are known in the carboniferous rocks of Canada. A Millipede found in the coal of Ayrshire, named *Euphoberia*, is four inches long, nearly a quarter of an inch broad, formed of thirty-six body rings, each with two pairs of legs. These myriapods are distinguished by possessing branched spines which are hollow. The American genus *Xylobius* has been found at Glasgow and Huddersfield, in the coal.

The spiders of the coal belong to a group known as the false scorpions, of which the type is the living genus *Phrynus*. *Eophrynus Prestwichi* is a well-known, though rare fossil from the ironstone of Dudley. It resembles spiders in having four pairs of legs, and a pair of palpi is seen. On the under side of the body are the openings of

six pairs of stomata from the tracheæ, which are developed as in insects. True spiders are found in the coal measures of Bohemia, Silesia, and of Illinois.

Another representative of this group of Arachnida is the scorpion, which is represented by the genus *Eoscorpius*. Scorpions are first found in the Silurian rocks. *Eoscorpius* found in the coal of Illinois, appears to be closely allied to a living Californian scorpion, of the genus *Buthus*; though the form found in the coal of this country agrees best with the genus *Scorpio*.

Insects are well represented in the coal. Coleoptera are known from beetles named *Curculioides* and *Troxites*. Grasshoppers are found, as are cockroaches. *Lithomantis* represents the living leaf-insect *Mantis*. The white ant occurs; along with a butterfly. Carboniferous insects are chiefly known from the coal-fields of the continent.

The fishes found in the coal measures include a number of sharks, known from their fin defences and teeth.

Labyrinthodont reptilia are referred to more than twenty genera. Many of these are from the Kilkenny coal-field, and Belgian coal-field. The remarkable genera, *Anthracosaurus* and *Loxomma* from the coal-field of Northumberland are among the largest of carboniferous genera. They are distinguished by having the teeth united to the jaw, without being in sockets. In some families the palate is covered with a large bone in the middle, named the para-sphenoid. The skull is sculptured as in crocodiles, and contains some bones which are not found in existing reptiles, especially behind the eye, where bone is absent in a crocodile.

CHAPTER XIV.

PERMIAN AND TRIAS.

THE deposits which rest next in succession upon the Carboniferous series are termed Permian, because they appear to be identical with the strata found in the Russian government of Perm. They had been termed Poikilitic, or variegated rocks; and sometimes the Pontefract rocks, from occurrence at that town in Yorkshire.

Marine beds in the east of England represent them between Hartlepool and Nottingham, but the Permian sandstones have sometimes been regarded as fresh-water and lacustrine deposits in the west and south-west of England. They appear to be unconformable to the underlying strata in some localities. In other localities there is no clear separation between the lower Permian rocks and the Carboniferous. Such conditions appear in Lancashire and Cheshire, and are regarded as occurring in Russia, and in North America.

The lower sandstones in Cumberland yield the characteristic genera of Carboniferous plants. It is therefore interesting that near Enville in Worcestershire, and in other localities, the Permian rocks contain angular boulders, which are polished, and scratched apparently by ice; though the scratched stones may not be evidence that glacial conditions prevailed in that district in the Permian period.

The Permian rocks of Great Britain comprise lower, middle and upper series. The upper and lower parts are sandstones and conglomerates, or

sometimes breccia derived from the Carboniferous limestone. The middle portion is a great wedge of magnesian limestone, resting upon the marl slate, 600 feet thick in the east of England, and 10 or 20 feet in the west. The upper sandstones and clays with gypsum, like the lower beds, are thick in the west and thin in the east: but are only about one-fifth of the thickness of the lower sandstone. The lower 3000 feet of variegated sandstone is identified with the German rothliegende. The marl slate is identified with the kupferschiefer, and the zechstein with the magnesian limestone. The lower Bunter of Germany has been compared with the gypseous marls of the Eden basin in Cumberland.

The magnesian limestone probably was originally an ordinary limestone formed of calcite, and the carbonate of magnesia was apparently infiltrated into it. There is no more singular deposit anywhere to be seen than the exposure of this rock at Sunderland, where some of the beds now consist of radiating concretions of globular form and variable size, giving the rock an appearance of being built of shot or cannon-balls.

The Permian age was a time of considerable volcanic activity, and interstratified beds of volcanic ash and lava are well seen in the country about Exeter, and in Ayrshire, as well as in Germany.

In other parts of the world the Permian formation attains a great development in thickness, and contains important beds of coal. The Gondwana rocks of India, which are probably comparable to the Permian of Russia, very closely resemble the Permian rocks of the Karoo in South Africa. Both contain coal, and the flora is probably Permian,

but several of the genera of ferns do not occur in Great Britain.

Among the fossils in the marine beds between Hartlepool and Nottingham the foraminifera include several existing genera. Neither the corals nor crinoids show any remarkable variation from carboniferous types, and in a general sense this is true of the shells, though a large number of the genera which characterise the primary period are absent. There are some characteristic genera of fishes like *Acrolepis*, but the most abundant fish type is *Palæoniscus.*

Fossil Reptiles of the Permian.

The Labyrinthodont reptilia, distinguished by having teeth blended with the jaw bones without being in sockets, are found in some British coal-fields, and are also known from Permian deposits. In Bohemia and in Saxony many small animals of diverse forms occur; some long and snakelike, and others like land salamanders. Some of these closely resemble fossils of the Kilkenny coal-field, as well as similar types from the coal-fields of Illinois, Ohio, and Nova Scotia, and are referred to the same genera. One of these Bohemian animals, named *Branchiosaurus*, still preserves in the fossil state a skeleton to the bony arches which supported gills. This old reptile, like some of the ancient fishes associated with it, may have breathed by gills as well as lungs, like certain of the living amphibia. This terrestrial life makes a close link between the Permian and Carboniferous periods.

The Permian rocks contain another extinct group of animals named Anomodontia, which

comprises the groups named Theriodontia, Dicynodontia and Pareiasauria. They are animals with depressed bodies rarely lifted high above the ground by their limbs, with relatively large heads, and types of dentition which are anomalous, because they closely resemble the teeth of different orders of mammals, while preserving tooth characters of reptiles and fishes. Nor is this resemblance to mammals limited to the teeth. It is seen in almost every part of the skeleton; and although there is no actual transition to mammals, isolated parts of the skeletons have been described as mammalian by different naturalists.

The Anomodont group is most widely developed in the Permian rocks of South Africa. It is well represented in the Permian of Texas, and other parts of North America. It is recorded from the Gondwana rocks of India, and from the Permian rocks of Orenburg in Russia. Anomodont reptiles have also been found in the red sandstones of Elgin. Those rocks were formerly classed as Old Red Sandstone, and subsequently as Trias owing to the affinities of their fossil reptiles, but on such evidence they may be Permian.

The Theriodont type generally possesses the three kinds of teeth which characterise mammals. The canine teeth are strongly developed. This is seen in the Russian genus *Deuterosaurus*, and in the South African genus *Lycosaurus*, both of which have the teeth in the front of the mouth larger than the sharp-pointed representatives of the grinder series placed at the sides. *Deuterosaurus* finds its place between the Theriodonts and Pareiasaurus. Some of the South African Theriodonts have the molar or grinder teeth compressed and

FIG. 18.—Skeleton of Pareiasaurus Baini, from Permian rocks in the Karoo, Cape Colony. Original in the British Museum. Showing bony scutes in the middle line of the back (after *Geological Magazine*)

notched like those of dogs, seals, and other carnivorous mammals. There are also types which have tuberculate crowns to the grinders adapted for crushing food, during which process the crowns become ground down, as among Insectivora and Rodents.

There are in the genus *Dicynodon* only two teeth in the upper jaw, which correspond to the tusks of the walrus.

In *Pareiasaurus* the surface of the skull is covered with an arrangement of bones which appears to be identical with that seen in the Labyrinthodonts. Labyrinthodonts were formerly grouped with the Amphibia, but may be closely related to the Anomodonts. Pareiasaurus appear to be in many ways transitional between existing reptilia and mammalia; in so far as can be judged from the skeleton. It is with existing marsupials and carnivora, and hoofed or ungulate mammals that the resemblances in the forms of the bones appear to be closest.

The Trias.

A glance at a geological map of England and Wales shows that the Trias, which extends to the south of the Pennine chain, between Nottingham and the North Staffordshire coal-field, rests unconformably upon the denuded edges of the Permian and Carboniferous strata. Great changes had taken place in the earth's surface after the deposition of the Permian rocks, and a commencement was made in the definition and uplifting of the Pennine chain before the Trias was laid down against its southern termination.

In England the Trias comprises two series of sandstones. The lower, named Bunter, consists

of conglomerates and sands, which are usually white, but sometimes red. There are some evidences that its upper beds were denuded before the overlying alternations of marls and sandstones, named the Keuper beds, were deposited. These divisions are regarded as corresponding to the upper and lower divisions of the Trias in Germany, between which the shell limestone, termed Muschelkalk, occurs, yielding numerous marine fossils, and many peculiar fossil reptiles.

These beds attain a thickness in Lancashire and Cheshire of 5200 feet. The Keuper is there twice as thick as the Bunter; but in Leicester and Warwickshire the aggregate thickness of both divisions of the Trias is less than 1000 feet; and of that the Bunter forms about one-tenth.

There is a southern thickening of the Trias in Somersetshire and Devon, where the red rocks are well exposed on the coast, and are about 2500 feet thick. There are few or no fossils in the Bunter.

The rock-salt of Cheshire occurs chiefly in the Keuper marl in two principal beds, as at Northwich, where each of the principal lenticular masses of salt is about 100 feet thick. Gypsum is also found in the marls, and is largely worked in Staffordshire. The occurrence of the salt may be attributed to the evaporation of an inlet of the sea; so that the process was substantially the same as that now going on in the salt-pans on the shores of the Mediterranean, where salt is obtained artificially by evaporation of sea-water. There appear to have been many of these ancient salt-pans. The lower bed at Northwich is about three-quarters of a mile in diameter. The salt has been preserved by the marl in which it is contained,

which is impervious to water. The gypsum has probably been formed out of the carbonate of lime of calcareous organisms, by the action upon them of sulphurous waters, such as result from the decomposition of iron pyrites, for Mr. Charles Darwin describes gypsum as formed in this way in lakes on the surface of South America.

In the neighbourhood of Storeton, between the Mersey and the Dee, an immense number of impressions of the feet of terrestrial animals are found, some of which are at present otherwise unknown. They may comprise the footprints of Dicynodonts, of Rhynchosaurian reptiles, and perhaps of *Hyperodapedon*, bones of which occur in Keuper beds in other parts of the country. The Keuper at Warwick yields evidences of the skull of species of *Labyrinthodon.* And near Bristol, carnivorous saurians, termed *Palæosaurus*, with piercing and cutting teeth, are found, which are closely allied to the great saurians of the Trias of Wurtemberg, named *Zandodon.*

The Stormberg beds in South Africa are probably of Triassic age, and contain saurians in some respects similar to those of Germany, such as *Massospondylus* and *Euskelesaurus*, and are found above the coal of Cape Colony. They all show some alliance with the *Megalosaurus* of a later age.

The saurians of the Muschelkalk in Germany include *Placodus*, which has the palate covered with large flat crushing teeth; and *Nothosaurus*, which appear to be intermediate between the Deuterosaurs of the underlying Permian rocks of Russia, and the long-necked Plesiosaurs of the Oolitic series above.

In Europe at least the plants of the coal period,

with the exception of *Calamites*, have disappeared in the Trias; and various types of Cycads come into existence, and do not differ appreciably from surviving forms in mode of growth and fruiting.

The Oldest Known Mammal.

The oldest known mammal is found in the upper part of the Trias or in the Rhætic beds. There are several species referred to the genus *Microlestes*. They are only known from isolated teeth and are referred to mammals because the roots of the teeth are divided. They occur in Wurtemberg, and at Frome, and Watchet in Somersetshire. The great milk tooth from Watchet is marked with seven ribs, like those on the premolar tooth of the living kangaroo-rat named *Hypsiprymnus*. The animal has therefore been regarded as a marsupial mammal. Animals with this type of tooth are found in subsequent periods of geological time. The lower jaw of a little mammal named *Plagiaulax* found in the terrestrial Purbeck beds at the close of the Oolites, has similar teeth. This type is repeated in the genus *Neoplagiaulax*, found at Rheims in the lower tertiary beds of the Paris basin. There is therefore reason to believe that very little change has taken place in the oldest type of mammal since its first occurrence in the Trias; and that it was essentially a Kangaroo-rat.

Peculiar marine fossils appear in the Muschelkalk. One of these is the Cephalopod shell *Ceratites*, which is exactly intermediate between the Carboniferous *Goniatites* which has the septa angularly folded and the newer *Ammonites* which has the folds of the septa digitated on both the front

and back margins. Subsequently, in the Austrian Alps, especially at Hallstadt on the north, and St. Cassian on the south, the Upper Trias abounds in shells which are a remarkable mixture of those which survive from the Primary period, such as *Orthoceras*, *Goniatites*, *Euomphalus*, *Murchisonia*, with the shells which are found in the overlying strata, such as *Ammonites*, *Belemnites*, *Nerinæa*, *Trigonia*, *Cardita*, *Thecidium*. Therefore the separation in life between the Trias and the Permian, although most marked, is not so absolute as it would have appeared to be if those Alpine deposits had been unknown. And the occurrence of genera which had characterised the primary strata, is the more interesting because other examples occur of similar survival of types of life from the primary time, in the occurrence of the genus Leptæna in the Lias, and of Spirifera in the Lias and Lower Oolites. Such occurrences prove that the change in life was a local change, and that the primary types became extinct gradually.

Newer than the Keuper is a series of beds in the west of England not more than 100 feet thick, known as the Penarth beds or Rhætic beds, from their great development in the Rhætic Alps. They are included in the Trias by many writers. William Smith referred to them as the White Lias, which is a compact limestone forming the top of the Rhætic series, in marked contrast to the Blue Lias above. The White Lias has occasionally been used as a substitute for lithographic slate, which it resembles in appearance. Dragon-flies, Cockroaches, Grasshoppers, and other insects are preserved in the White Lias.

Fossils are plentiful in the underlying black shales, at the base of which is the Rhætic bone

bed, full of the remains of fishes and reptiles. Beneath the black shale are the tea-green marls, which pass down through other marls into the Keuper beds. Species of the existing Australian fish *Ceratodus* evidenced by teeth here occur; associated with extinct genera of sharks, such as *Hybodus* and *Acrodus* which characterise the Oolites.

The common sea-shells of Rhætic age include a Cockle and a Pecten, such as might occur on our own shores at the present day, associated with a species of Avicula, a horse-mussel and an oyster. At least one large terrestrial Saurian with teeth like Megalosaurus occurs in Rhætic beds in Somerset. The Ichthyosaurs and Plesiosaurs, which are found for the first time in this stratum in this country, do not differ from those of the newer beds.

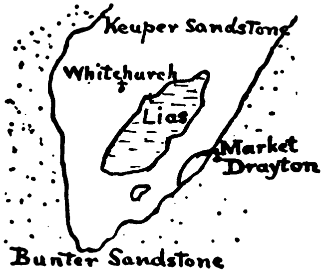
Rhætic strata occur in most European countries in which the Trias is developed; but are nowhere more grandly exhibited than in the Rhætic Alps of Lombardy and Austria.

CHAPTER XV.

THE LIAS.

In the Jura range between France and Switzerland, which furnishes the continental type for rocks like our Lias and Oolites, the Jurassic beds are commonly divided into three parts, named Black, Brown and White. The Black Jura corresponds generally with the Lias; the Brown Jura with the lower Oolites; and the White Jura with

the upper Oolites of England. These three divisions in this country are greatly subdivided by differences in mineral character, as well as by fossils.



MAP OF AN OUTLIER.
FIG. 19.—Map of an outlier of Lias between Market Drayton and Whitchurch, proving that the Lias was spread over the West of England.

The Lias is generally recognised by the great breadth of country that it covers between Whitby and Lyme Regis, by its thickness, and its many sub-divisions which are traced through the country. It is, as a rule, a blue-black clay alternating with thin, regular layers of earthy limestone, so that the alternations of clay and limestone which characterise the Rhætic beds are continued, with a multitude of repetitions. The Lias limestones have sometimes a tendency to be brown. The thickness of the Lower Lias varies between 500 feet at Lyme Regis and 800 feet on the Yorkshire coast. The common Lias Oyster is the Gryphæa incurva. Occasionally, in the country towards Frome the Lias almost thins away where it rests against the Carboniferous limestone, and it is probable that the different beds vary in thickness locally. The marine and terrestrial saurians are found chiefly in the lower beds of the Lower Lias, in the south of England. They include both Ichthyosaurs and Plesiosaurs. Nearer the top of the Lower Lias *Scelidosaurus*, a terrestrial ar-

moured saurian is found, which in many ways resembles the Iguanodon of a later period, and is the type of a family with vertically serrated teeth named Scelidosauridæ.

The fossils which are most abundant are a multitude of extinct species of *Ammonites* and *Belemnites*, together with an oyster with an involute mode of growth, known as the genus *Gryphæa incurva*, the devil's toe-nail of the Dogger fishermen. But with such exceptions the great multitude of the fossils belong to existing genera. Among which are the bivalves *Lima*, *Pecten*, *Pinna*, *Pholadomya*, *Astarte*, *Avicula*, *Modiola*, *Trigonia*, *Plicatula;* and the Univalve shells *Littorina* and *Pleurotomaria* are abundant. Species of the genus Ammonites give names to sub-divisions or zones of the Lias. Some genera such as *Cardinia* and *Hippopodium* are only found in the Lias.

FIG. 20.—Gryphæa incurva: Lias.

There is perhaps no sharp separation to be drawn between the Lower and Middle Lias. The two beds are conformable to each other, although the fossils distinguish them, and there is some difference in their mineral character. The Middle Lias comprises the marl stone, which forms an escarpment in the middle of England; and it also includes the ironstone series, which is well developed in the Cleveland district of Yorkshire,

and southward through Lincolnshire into Oxfordshire. The Middle Lias is about 250 feet thick on the south coast; and 140 feet thick on the Yorkshire coast. Near Cheltenham the lower part includes some grey sand, and is about 150 feet thick. The difference from the Lower Lias in fossils is chiefly in the species of *Ammonites* and *Belemnites*. Some of its upper beds are known as the Belemnite beds, from the abundance of this fossil. In these beds many star fishes of the genus *Ophioderma* are found, both on the Yorkshire coast, and near Charmouth.

FIG. 21.—Cardinia Listeri: Lias.

The Upper Lias is usually very thin on the coast of Dorsetshire, about 70 feet, including the associated sands near Charmouth. But it thickens northward to 300 feet near Cheltenham, and 400 feet further north in Bredon Hill; maintaining a thickness of 300 feet in Leicestershire, but thinning in Lincolnshire and Yorkshire to 200 feet or less. On the Yorkshire coast it is often known as alum shale, alum having formerly been obtained from the cliffs and manufactured from the shale. Near the base there are beds of jet, in which the rings of growth of the coniferous trees out of which it was formed, may occasionally be observed. In the Upper Lias at Ilminster many Ichthyosaurs, Plesiosaurs, and crocodiles of the group Teleosauria are met with. A little higher up, in the zone of the *Ammonites communis* and *Ammonites bifrons* near Whitby, the same

genera occur, though they are sometimes met with in the underlying zone of *Ammonites serpentinus*, which yields the jet.

The Upper Lias of Gloucestershire and Warwickshire contains a considerable number of insect remains, probably derived from the forests in which the coniferous trees grew, which appear to have been allied to the living Araucaria. There are also the remains of Cycads, such as *Zamia*, and of a few ferns; so that, although there is no such evidence of a land surface as in the Triassic period, the occurrence of insects in districts which, in the previous period of the Trias, yield the remains of terrestrial animals, appears to show that the physical change which brought the Lias to an end, and caused the Midford sands to be superimposed upon it, was substantially a bringing back again in part, by means of upheaval, of the shallow water conditions which prevailed in the Trias period.

The yellow sands, 200 feet in thickness at Bridport, which pass northward into Somersetshire and Gloucestershire, under the name of Midford sands, gradually thin away. But since they indicate the same conditions as afterwards reappear in the Northampton sands in the middle of England, they may be grouped with the Oolites rather than with the Lias.

CHAPTER XVI.

THE OOLITES.

THE Oolites are granular limestones of limited extent, contained between clays, which in Great Britain range between Dorsetshire and the north coast of Yorkshire. They form three limestone terraces in the south of England, each of which rests on a clay, and hence have sometimes been named Lower, Middle, and Upper. It is more convenient to adopt two divisions. The Lower Oolites include every bed above the Lias to the Cornbrash. The Upper Oolites extend from the Oxford Clay to the Portland Oolite.

Lower Oolites.

The *Midford Sands* are seen near Bath making the base of the Oolites. The sand appears to have been derived from the south, because the whole of the Lower Oolites are represented by sands in Dorsetshire. The Midford Sands disappear to the north of the Cotswold Hills, probably because they are represented there by clay which is not distinguished from the Lias.

The beds named *Northampton Sands* occur in the same geological position in Northamptonshire. They are about 70 feet of brown sands and yellow sandstone, with ironstone, which is a valuable iron ore. They are capped by grey and white sand, containing beds of lignite, which may have accumulated in an estuary. Their fossils are mainly those of the Inferior Oolite; and they are probably a geographical continuation of the Midford Sands.

FIG. 22.—Skeleton of Ichthyosaurus from the Lias of Wurtemburg. The form and position of the dorsal and caudal fins and limbs are preserved by the skin, now black (after E. Fraas).

In Yorkshire the beds which rest on the Lias are known as *Dogger*. They are about 90 feet of yellow sand covered by concretions of Oolitic ironstone, usually sandy. Like the Northampton sands, they are capped by current-bedded sands and shales among which are beds of impure coal. The fossils of those estuarine sands include ferns, a large *Equisetum* often found erect among the blown sand, and the Cycad *Zamia*. They indicate an old land surface. The beds which rest upon these sands show a similar want of continuity where they are exposed at the surface of the country.

The *Inferior Oolite* is limited to the west of England. In the Cotswold Hills it is about 250 feet thick, mainly limestone. At its base is the pea grit, with concretions about the size of peas. Above it are the Oolite limestones with texture like the hard roe of fish, known to builders as freestone, termed Roe-stone, which alternate with marl. A little sand remains when the limestone is dissolved. The rock thins away to the east beyond Woodstock. Its fossils include *Terebratula fimbria*, *Pholadomya fidicula*, *Ostrea Marshii*, *Clypeus plotii*.

In Northamptonshire the beds are replaced, first, at the base by a thin bedded, shelly limestone used for roofing, known as *Collyweston Slate*. It is sometimes 20 feet thick. The great mass of the Inferior Oolite is represented by a limestone known as *Lincolnshire limestone*, which thins away to the north and south. It is 200 feet thick at its maximum, and forms an escarpment terrace in Northamptonshire and Lincolnshire.

In Yorkshire this period of time is repre-

sented by the middle estuarine beds with bands of coal and plants, seen in Gristhorpe Bay; above which is the marine Scarborough limestone, with the Inferior Oolite fossil *Ammonites Humphreysianus*.

The Fuller's Earth in the south of England caps the Inferior Oolite, and divides it from the great Oolite. It is a series of clays, marl, and earthy limestone known as Fuller's Earth rock. The stratum, sometimes blue, sometimes yellow of Fuller's Earth of commerce is only a few feet thick. The Fuller's Earth in Dorsetshire is estimated at 400 feet in thickness. In the Midland counties the Upper Estuarine beds represent it with 30 feet of sands, clays and limestones. On the Scarborough coast their thickness is 200 feet, and, besides remains of terrestrial plants, they contain the fresh water pond shell *Anodonta*.

The *Great Oolite* is more local than the Inferior Oolite. At Minchinhampton it includes shelly beds. At Bath it is a freestone 50 feet thick, sometimes with oolitic texture, sometimes marly. It is seldom oolitic to the north of the Cotswold Hills.

To the north-east, the Bath oolite is represented by the *Stonesfield slate*, a concretionary thin-bedded limestone, formed in part by the destruction of older beds of oolitic rock. It indicates near proximity to land. Its fossils are the fronds of ferns, foliage and fruits of cycads, branches of coniferous trees. There are beetles, dragon-flies, butterflies, and other insects. Lower jaws of four kinds of mammals have been found, named *Amphitherium*, *Amphilestes*, *Phascolotherium*, and *Stereognathus*, which, on the evidence of their teeth, appear to be allied to Marsupials, though a

thigh bone resembles that of the Australian duck bill *Ornithorhynchus.* Flying saurians are named Rhamphocephalus. Long snouted types of crocodile occur, and remains of the great terrestrial carnivorous Megalosaurus, which appeared first in the Inferior Oolite. All these fossils are in a bed full of marine shells.

About Bath and in Dorsetshire the Great Oolite is succeeded by a brown clay crowded with the *Apiocrinus*, or pear encrinite, which has a cylindrical stem. This clay, named *Bradford clay*, separates the Great Oolite from the thin-bedded *Forest marble* above it. That shelly limestone at Enslow Bridge near Oxford, at Chipping Norton, and other localities yields the remains of *Cetiosaurus*, which is the largest terrestrial fossil reptile found in England.

In Northamptonshire and Lincolnshire there is a clay above the Great Oolite limestone, in the position of the Forest marble and Bradford clay, called the *Blisworth clay.*

All these irregularities in mineral character of the Lower Oolites as they are traced through England may result from the sinuous contours of bays and promontories of the shores at the time of their depositure, which did not correspond with the line along which the several deposits come to the surface of the country at the present day.

Cornbrash is the name given to a shelly limestone which closes the Lower Oolitic period. It is rarely more than 10 to 15 feet thick. Many of its fossils are like those of the Inferior Oolite. The most characteristic species is the *Avicula echinata.* It is the first deposit since the Lias which extends continuously through England,

and is seen between Scarborough and Weymouth. It is evidence of a change in the tilt of the sea-bed, which makes a break in the succession of the strata.

Upper Oolites.

There is no break in the order of succession of the Oolitic rocks above the Cornbrash, which would divide them into Middle and Upper Oolites. The differences in mineral character between the several beds are such as may be attributed to changes in level of the old land from which the sediments were derived, which removed the source of the deposited material from time to time, to greater distances.

The first effect of such an upheaval is seen in the *Kelloway Rock*, which forms concretionary sandy beds, and yellow sands and limestones 80 feet thick on the Yorkshire coast. It is said to occur in Bedfordshire. It is named from occurrence at Kelloway Bridge in Wiltshire. This distribution may be connected with proximity to the Mendip ridge in the latter case, and connected with the Pennine chain in the former. The conditions which produced the Stonefield slate probably produced the Wiltshire Kelloway rock; and the conditions of the sand beds in the Yorkshire Lower Oolites are approximated to by the Yorkshire Kelloway rock. This deposit is more important in France.

The *Oxford clay* is manifestly the consequence of a depression which prevented the coarse sandy sediment from reaching so far out from its source as in the previous age. This clay, which is 170 feet thick in Yorkshire, and 600 feet thick in Dorset, is therefore superimposed upon the

Kelloway rock. Near its base, about Peterborough, the Oxford clay abounds in remains of timber trees, apparently coniferous. Its plant remains also include Cycads. It yields the terrestrial reptiles *Cetiosaurus* and *Omosaurus*, with Teleosaurian crocodiles, *Ophthalmosaurus*, which is an Ichthyosaur with three bones in the forearm instead of two. The big headed Pliosaurus is common; Murænosaurus is a long-necked pliosiosaurian with single headed ribs to the neck, and two bones in the forearm. The common shells in the Oxford clay are the oyster *Gryphæa dilatata*, *Belemnites hastatus*, *Ammonites Duncani*, and *Ammonites cordatus*. The *Ampthill Clay* and *Oxford Oolite* rest upon the Oxford clay. The Ampthill clay is seen between Ampthill in Bedfordshire and Acklam Wold in Yorkshire.

The Coralline Oolite interlaces with the clay in Bedfordshire by a number of thin beds of blue

FIG. 23.—Belemnites Oweni, an internal shell of a kind of cuttle-fish. The "Guard" is broken to show the conical phragmacone which penetrates into it. Oxford Clay.

earthy limestone. Traced southward by Shotover, it forms two divisions; and at Weymouth there is the sandy lower calcareous grit well defined, and an upper grit or sand which passes up to the Kimeridge clay. In Yorkshire this Oolite extends through the Howardian Hills by Malton, through the Vale of Pickering to Filey. At Upware, on the river Cam, a small reef full of corals appears to result from the Carboniferous limestone having furnished calcareous matter to the

neighbouring sea. The reptiles of this age, *Omosaurus* and *Pliosaurus*, are like those of the Oxford clay, but a great Megalosaurian, named *Streptospondylus*, has also been found at Weymouth and Malton in Yorkshire.

The *Kimeridge Clay.*—The reef of limestone at Upware appears to be a dividing point for the Kimeridge clay, which comes next in vertical succession. In Cambridgeshire it is about 40 feet thick, but thickens south-west to Dorsetshire to more than 600 feet thick, and its northern thickening to Yorkshire is almost as great. This clay contains inflammable beds known as Kimeridge coal, which divide into thin sheets like paper, and are full of marine fossils. In Dorsetshire the clay is used as fuel, and has been used in making paraffin candles, and to produce gas for illumina-

FIG. 24.—Section showing the succession of strata east of Oxford.

tion of the neighbouring villages. These clays are full of beds of concretions of earthy limestone, named septaria, which are each 2 or 3 feet in diameter.

The oldest known representative of the Iguanodon is found in this clay at Cumnor. And between Ely in Cambridgeshire and Swindon many fossil reptiles are found, such as Teleosaurian crocodiles, peculiar turtles and Ichthyosaurs. *Colymbosaurus* is a long necked Plesiosaur with single heads to the neck ribs, distinguished by the massiveness of its arm bones, and by having three

bones in the forearm instead of two. Omosaurus is a large land saurian found at Swindon. The common shells of the clay include *Ostrea delto dea*, *Exogyra virgula*, *Lingula ovalis* and *Ammonites biplex*.

The Solenhofen slate of Bavaria makes known numerous insects and other forms of terrestrial life of this period, including the oldest known bird.

The Oldest Known Bird.

A bird is known by its feathers; though there is no reason why the covering to the skin should not be as variable in this group of animals as among reptiles or mammals. It is therefore remarkable that the oldest known bird named *Archæopteryx* has feathers as well developed as in the existing representatives of the class and similarly arranged. It is found in the lithographic slate of Solenhofen in Bavaria, which is of about the age of the Kimeridge clay, in the Upper part of the Oolites. The animal is an elegant slender bird which is chiefly remarkable for showing teeth in the jaws. About twelve, short and conical, occur on each side in the upper jaw. The skull is about two inches long, shaped like the skull in many existing birds, with a circle of sclerotic bones defending the eye.

The neck and back are each about $2\frac{3}{4}$ inches long, and there is a slender rat-like tail, of more than twenty elongated vertebræ, which is $6\frac{1}{2}$ inches long. The fore limbs are as well developed as the hind limbs. But they differ from existing birds in the bones of the metacarpus not being blended together, and in the three digits terminating in sharp claws. The number of the phalanges in the

three fingers is 2, 3, 4. They are thus similar to the digits of the hind limb, and are apparently

FIG. 25.—Skeleton of the oldest-known bird, *Archæopteryx macrura*, showing impressions of the feathers on the wings, legs, and tail. From the lithographic stone of Solenhofen (after Dames).

capable of being applied to the ground like the fore limbs of a quadruped, although the great development of the feathers attached to the arm bones demonstrates that the wings were

constructed on the same plan as in existing birds.

The femur or thigh bone is about two inches long; the drum stick is more than two inches and a half. And the slender metatarsus is about an inch and a quarter long. The three points of dif-

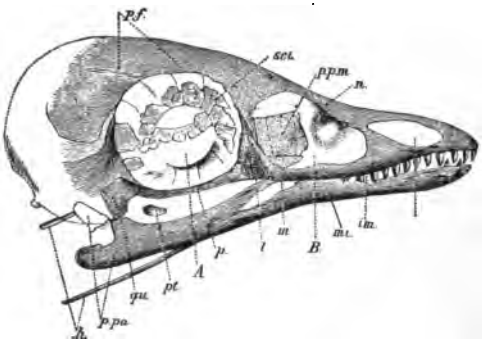


FIG. 26.—Skull of the oldest-known bird with teeth. Archæopteryx macrura (after W. Dames). *A.* orbit of the eye. *B.* pre-orbital vacuity. *C.* nostril. *Scl.* circle of bony plates round the eye. *h.* tongue bones. *mi.* lower jaw. *m* and *im.* jaw bones. *l.* tear-bone. *n.* nose-bone. (After Dames.)

ference from existing birds are, the elongated tail bearing feathers on each vertebra, the teeth, and the claws on the three digits of the hand.

Close of the Oolitic period.

A great change in life took place between the Kimeridge clay and the Portland Oolite which rests upon it. And although the granular Oolitic

texture, which the Portland limestone shows in the south of England, has caused it to be associated with the older Coralline Oolite, and Lower Oolites, it yet marks the beginning of a great uprising of the sea-bed, which extended eastward from the Mendip Hills during the succeeding periods of time. Many of its fossils may justify its position in the Oolitic series, but the physical conditions of upheaval, and representation by limestone and sand, appear also to link it with the great terrestrial epoch of Purbeck and Wealden beds, which form a portion of the Neocomian period of time.

The Portland strata are almost limited in a recognisable form to the south of England, though the horizon is defined by fossils in the clay beds at the top of the Kimeridge clay in Filey Bay. A thin sandy layer with characteristic Portland fossils caps the Kimeridge clay through Lincolnshire, Norfolk, and Cambridgeshire. It is not always possible to draw a line between this feeble representative of the Portland sand and the overlying sand termed Neocomian, so that the Portland sand appears like the beginning of the shore conditions, which lasted in the area of South Britain till the close of the Lower Greensand.

On the Yorkshire coast there is no break whatever in mineral character from the Kimeridge clay to the Hunstanton Red Limestone at the base of the chalk.

Among the fossils of the Portland beds several species of *Perna*, *Astarte*, etc., are found which resemble fossils of the Kimeridge clay, but there are also species of *Cyprina*, *Pecten*, *Cerithium*, etc., which resemble Neocomian forms. *Lucina Portlandica* is one of the characteristic bivalve fossils.

CHAPTER XVII.

NEOCOMIAN.

THE Neocomian period of geological time is completely represented in Great Britain in the Speeton clay, which is about 300 feet thick, and seen to the north of Flamborough Head. The basement bed of this deposit is the Coprolite bed which divides it from the Kimeridge clay on which the Speeton clay rests. That bed is a layer of nodules of phosphate of lime, which apparently were formed about fossils, like similar beds of phosphate of lime in newer deposits in Bedfordshire and Suffolk. This layer of phosphates marks a change in the life; so that the shells which characterise the Kimeridge clay below do not pass above it. It was formerly supposed to occur at the top of the Portland beds, but the Ammonites regarded as Portlandian occur above this junction bed.

There is therefore some ground for regarding the Speeton clay above the Coprolite bed as representing in unbroken marine sequence the geological ages which in the south of England are partly lacustrine, partly terrestrial, and partly marine, and known as the Portland beds, the Purbeck, and the Wealden beds, and the Lower Greensand.

The lowest division of the Speeton clay is known as the zone of *Belemnites lateralis*. The *Lucina Portlandica* is found in the Coprolite bed, and a variety of the *Exogyra sinuata* appears somewhat higher up. The next division is the zone of *Belemnites jaculum*, which ranges through about

120 feet of clay in which there is a large number of characteristic Ammonites, with species of Terebratula and Rhynchonella. The third zone is that of the *Belemnites semi-canaliculatus*. In this zone in the *Ammonites Deshayesii* found in the Lower Greensand of the south of England. The uppermost zone of the Speeton clay is that of *Belemnites minimus*. This fossil which in the south of England abounds in the Gault, here occurs in association with *Inoceramus concentricus*, *Inoceramus sulcatus* and *Nucula pectinata*, which are also common gault species. The clays, which are mostly dark blue, and blue black, become red at the top, so that there appears to be a transition from the red clay to the argillaceous red limestone, known as the Hunstanton Limestone, or red chalk of early writers.

The top beds of the Speeton clay may therefore be newer than the Neocomian of which the upper limit is the Lower Greensand of the south of England. The other beds give a threefold division. So that the Portland and Purbeck limestones of Swindon correspond to the *Belemnites lateralis* beds, which are represented by the Upper Volga beds of Russia. The middle beds, apparently, would correspond to the Wealden period of the south of England, Belgium, and Hanover, while the zone of *Belemnites semi-canaliculatus* corresponds to the Lower Greensand.

While these beds were being laid down in a region which underwent but little change of level, so that an uninterrupted deposit of clay was accumulated, the land was upheaved, further south, into those shallow water conditions, of which the Portland beds are evidence, which pass without an appreciable break into the lacustrine and ter-

restrial Purbeck series. There is nothing to show that the terrestrial surface was more or less than an enlargement of the land which in previous ages of secondary time had supplied the insects, mammals, plants and terrestrial reptiles which are found in various beds of the Upper and Lower Oolites, and which, by its varying elevation, had effected the distribution and nature of the sediments, all through the lower secondary period.

The limestone beds appear to have owed their existence largely to the influence of the Carboniferous limestone, for many evidences are found that it was repeatedly denuded, while the sandstones and clays were supplied partly by sediments derived from denudations of older slatey and schistose rocks. The existence of the Purbeck beds, which in Dorsetshire are alternations of thin-bedded white limestone, with bands of dark-coloured clay, shows that the streams of fresh water coming from off the land into the lake, charged the fresh water with carbonate of lime, just as they had previously charged the sea; while the uplifting of the earth's surface above the sea-level was so gradual that there is no break between the marine and fresh water beds. Near the base of the Purbeck beds in Dorsetshire an old land surface is found, known to the quarrymen as the Dirt Bed. It is well seen in the cliffs of Lulworth Cove in the Isle of Purbeck, and in the Isle of Portland. Here coniferous trees, sometimes a foot or two in diameter, lie prostrate, but the roots and lower parts of the trunk remain erect as they grew. Some of the coniferous trees show nearly 200 rings of annual growth and a length of sixty feet. Among

them are the short stems of Cycads, which resemble the living *Cycas revoluta.*

The Lower Purbeck also contains a multitude of insect remains, on several different horizons. They are chiefly in cream-coloured marl, and include the wing cases and bodies of beetles, dragon-flies, and other insects.

A terrestrial surface at the base of the Middle Purbeck is evidenced by many jaws, and a few other remains of small mammals. They appear to be little insectivorous marsupials, such as *Triconodon*, *Spalacotherium*, and the type like the kangaroo-rat, which is named *Plagiaulax.*

The Middle Purbeck includes some marine layers with cockle shells, oysters and pectens, with occasional ripple-marked sandstone. The marine beds alternate with the fresh-water beds, in which the common shells which live in existing ponds, *Paludina*, *Planorbis*, *Physa*, etc., appear for the first time.

The Upper Purbeck beds are interesting, first, for yielding the grey, Paludina marble, anciently used for decorative carving and monuments in the interior of churches; and, secondly, for the number of its fresh-water tortoises, named *Pleurosternon*, which differ from their living allies in having an extra pair of bones, stretching over the middle of the breast-plate, known as the plastron.

In Swanage Bay the overlying Wealden beds differ from the Purbeck beds in being sands and clays. In the boring near Battle in Sussex, the Purbeck beds, formerly known as the Ashburnham beds, contain some important layers of gypsum, but no other calcareous deposits; and are like the Wealden beds in mineral character.

The Wealden strata exhibit two types. In Dorsetshire and in the Isle of Wight they comprise alternations of numerous beds of grit, sand and clay, frequently of the most brilliant red colour. A few marine shells, species of Pecten, occur in the lower Wealden beds of the Isle of Purbeck. In the Isle of Wight they have yielded multitudes of vegetable remains, among which are pine cones, and especially the fossil forest of Brook, where, however, the great forest trees appear to be drifted and water-logged. In these beds have been found the remains of many extraordinary terrestrial reptiles. The *Ornithocheirus* type of Pterodactyl appears, which has the earlier joints of the backbone blended together, as in the frigate bird. There is a terrestrial saurian named *Polacanthus*, which had the lower part of the body covered with a complete shield like that of an armadillo. Associated with it is the Belgian *Iguanodon*, the great Cetiosaurian named *Ornithopsis*, and the genera named *Hypsilophodon*, *Sphenospondylus*, *Vectisaurus*, etc.

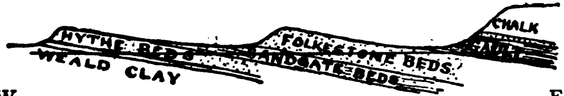
Further to the north, in the typical Wealden country of Kent, Surrey, and Sussex, these beds, instead of being multitudinous and irregular, become separated into great divisions of tolerably uniform mineral character. The Ashdown Sand is in the main a hard yellow sandstone. The Wadhurst Clay above it is a number of alternations of shale and hardened sand frequently ferruginous, with plant remains. The Tunbridge Wells Sand is about 150 feet of sandstone more or less divided by thin beds of clay, which may thicken locally. Above these beds, which are named Hastings Sand, comes the Weald Clay, which is 900 feet thick in the south-east of Kent,

and 400 feet thick in the west of Surrey. It is full of bands of fresh-water limestone, formed of fresh-water shells, especially Paludina.

In various localities in Sussex, particularly near Hastings, the footprints of *Iguanodon* have been found, and both there and at Cuckfield a multitude of bones occur. They include small species of Plesiosaur of the genus *Cimoliosaurus* and an Ichthyosaur possibly estuarine, together with a group of terrestrial saurians, entirely different from those of the Isle of Wight. These remains include *Pelorosaurus*, the *Iguanodon Mantelli*, *Suchosaurus* and *Megalosaurus*, as well as fresh-water tortoises. Many plants are met with on this horizon, including some ferns, like *Sphenopteris*, with the fronds well preserved; and numerous Cycads. Fresh-water shells include the existing *Unio*. The terrestrial fauna is very imperfectly known in comparison with that buried in the deep valleys near Mons in Belgium, from which entire skeletons of *Iguanodon* and other reptiles have been obtained. Along the northern outcrop of the Neocomian strata, by Farringdon, Potton and Upware, numerous remains have occurred of *Iguanodon*, *Megalosaurus*, and other terrestrial saurians like those of the Weald, and with them are remains of Cycads, *Pandanus* and Pines. On this outcrop the Neocomian Sand rests successively on the Kimeridge Clay, Ampthill Clay, and Oxford Clay as at Sandy and Woburn in Bedfordshire, showing that an unconformity separates the Neocomian strata from the Oolites in the middle of England.

The Lower Greensand is a marine bed which extends over the fresh-water series of the Weald. But beyond the Wealden area the sands are

termed Neocomian; because, although they exhibit a threefold division, it is difficult always to prove that these parts correspond to the Portland and Purbeck, Weald, and Lower Greensand respectively. In the Isle of Wight, the Lower Greensand consists of a large number of alternating beds of sand and clay, more than 900 feet thick. More than eighty distinct layers have been grouped into sixteen beds. So that the conditions of deposition of the Weald seem to have continued through the succeeding epoch of time; and occasionally the remains of an *Iguanodon* became floated into the Lower Greensand from land diminished by depression of its level. There is the same correspondence of the Lower Greensand to the Wealden beds in stratigraphical succession in the typical Wealden area of Sussex. The Lower Greensand is divided, in the section



W. E.

FIG. 27.—Section from Folkestone to Hythe, showing above the fresh-water Weald Clay, the divisions of the marine Lower Greensand, named Atherfield beds, Hythe beds, Sandgate beds, Folkestone beds.

between Hythe and Folkestone, into the Atherfield Clay at the base, which is sometimes a marine clay resting on the Weald Clay, and sometimes loose sharp sand. Secondly, the Hythe beds (or Kentish rag) are alternations of thin bedded limestone and sand with beds of chert. Thirdly, the Sandgate beds are sandy clays not very coherent, often green, like the underlying

beds. And fourthly, the Folkestone beds are usually yellowish, unconsolidated, and appear to correspond to the ferruginous sands of Shanklin in the Isle of Wight. Fuller's earth occurs at many horizons in the Sandgate beds. The Hythe beds occasionally contain beds of chert, derived from the growth and breaking up of siliceous sponges. Near Maidstone it has yielded boulders of granite, which may have been the anchor stones of marine plants like *Fucus*. Remains of terrestrial plants and of *Iguanodon* indicate near proximity of the Maidstone area to land, which is paralleled in the Isle of Wight.

CHAPTER XVIII.

LOWER CRETACEOUS STRATA.

Ever since the Carboniferous period the influence of a dividing line extending east to west, due to elevation of the rocks between Worcestershire and Lincolnshire, has been more or less persistent. It has influenced the mineral character of strata and distribution of life. It has given a distinct character to the Oolitic rocks south of Banbury, to that shown by the succession of rocks further north. The same geographical conditions separate the Neocomian rocks north and south of the land barrier indicated on the south by the Purbeck and Wealden rocks. A like physical difference is seen in some of the Cretaceous rocks.

In so far as can be judged by fossils, the change from Speeton clay to Hunstanton limestone took place in the middle of the Gault; since the fossils

in the bottom beds of the red limestone include the same Gault species as are found in the top beds of the underlying clay.

A similar transition in physical character is seen in Norfolk from the brown sands, locally termed Carstone at Hunstanton, to the sandy Hunstanton limestone which there rests upon it. This succession has sometimes led to the belief that the upper part of those sands is of the age of the Lower Gault.

But while there is an apparent conformity of the Cretaceous to the Neocomian beds on the east coast of England, at Speeton there was a manifest change in the tilt of the land further west, which caused the sea at that time to extend over the edges of the older Secondary strata. This is seen in land in the district which is now East Yorkshire by the deposit of the Hunstanton limestone which covers the edges of the Oolitic rocks. There appears to have been a similar depression of land at the same time to the west, in Dorsetshire and Devonshire, which resulted in the deposition of sands, known as the *Blackdown Greensand*, over the whole of the Lower Secondary rocks, and partly upon the Carboniferous rocks about Exeter,

FIG. 28.—Ammonites Deshayesii, from near the base of the Lower Greensand, Atherfield.

at the time when these cretaceous beds began to be formed. There are thus sands in the west in Dorset and Devon, which appear to represent a part, if not the whole, of the Gault; perhaps the Upper Gault, and the Upper Greensand. There is a Red Limestone in the north-east from Norfolk to north of Flamborough, which is a similarly undivided deposit. Placed geographically between these sands in the south-west and limestone in the north-east, are the strata known as Gault and Upper Greensand.

The *Gault* rests on Lower Greensand and Neocomian Sands. It is a blue micaceous clay, dark in colour in the lower part, where it is rich in fossils, and full of layers of concretions of phosphate of lime, which contains a large amount of iron pyrites in some localities. Its thickness in the south of England is about 150 feet, but it thickens to more than 200 feet at Hitchin; and one boring at Soham is said to have passed through 450 feet

E. W.

FIG. 29.—Cliff section, Hunstanton, Norfolk. Upon the brown Neocomian Sandstone is the red Hunstanton Limestone, four feet thick. The Lower Chalk rises from the beach to the top of the cliff, the dip being east.

without piercing it. Yet it thins away in the south of Norfolk, and there develops calcareous beds in

its upper part, which probably show that the Hunstanton limestone, which first begins to be recognised near Sandringham, includes the Upper Gault. The Gault extends as a clay all round the Weald, and through the Isle of Wight; so that its distribution is connected with the area occupied by the Wealden beds; and the changes of level by which that district was effected.

The *Upper Greensand* generally follows the distribution of the Gault; but there are certain areas from which it is absent as a recognisable sand. It is well developed in the Isle of Wight, and extends from Eastbourne through the South Downs and through the greater part of the North Downs; but there is no deposit of a sandy nature in the Maidstone country, found between the Gault and the chalk, which pass insensibly into each other. From Wiltshire the Upper Greensand extends to Tring, as a green sand, which is there about 30 feet thick; east of Tring its sandy character is lost. It has been found by a well boring again to put on the character of a green sand under Norwich. All the intervening country, which Professor Hull regards as having been land, during the deposition of the Carboniferous limestone, is covered with a thin bed known as the *Cambridge Greensand*, which is not more than a foot or two in thickness, and consists of nodules of phosphate of

FIG. 30.—Ammonites planulatus, Cambridge Greensand.

lime embedded in a paste of green grains of glauconite and marl, which entombs the most remarkable assemblage of fossils yielded by any formation in Britain.

When this bed is traced north it is lost; and in so far as can be judged from physical evidence, and its fossils, it has merged in the Hunstanton limestone, which divides into three thin beds. The middle layer of that rock is largely formed of concretions of phosphate of lime. At the base of the chalk wolds the limestone augments from 4 feet at Hunstanton to a considerable thickness at Speeton, where its upper beds become very irregular, and pass in to the white chalk without stratigraphical planes of separation. The irregular diffusion of the red colour in parts of the chalk would appear to indicate that the colour has an organic origin.

FIG. 31.—Part of the stem of an Encrinite (screw-stone), derived from the Carboniferous limestone found in the Cambridge Greensand.

The succession of the Upper Greensand upon the Gault is manifestly a consequence of upheaval of the old land from which the Upper Greensand was derived, bringing the source of the sediment nearer; so that it became coarser. The Gault at Ware rests directly upon the Wenlock limestone. At Cheshunt it rests upon the purple Devonian mudstones. Therefore this eastern country of England gives no evidence of having been submerged during all the Secondary ages till the Gault sea spread over it, and Gault was laid upon

it. And since some fossils, like those of the Carboniferous limestone, obviously derived, have occurred in the Neocomian beds of Upware, and in the Cambridge Greensand (Fig. 31), it is probable that the upheaval which brought about the formation of the Upper Greensand, raised the area of ancient rocks beneath the Gault. It became too shallow for the accumulation of anything but the phosphatic products of marine animal and vegetable life, boulders of the parent rocks, slates, schists, quartzites, granites, of the neighbouring land; and the multitudinous remains of Cimoliosaurus and Ichthyosaurs, and Chelonians; together with true lizards, allied to the monitor; and crocodiles of existing types. There are many terrestrial saurians allied to the armoured *Scelidosaurus* of the Lias, a score of Pterodactyls of all sizes of the genus Ornithochirus. One Pterodactyle, at least, is toothless. This type, which has smooth jaws like the jaws of a bird, is named *Ornithostoma*. The oldest known British bird is found in this bed. It is allied to the divers.

Cretaceous Birds.

The oldest British fossil bird is found in the Cambridge Upper Greensand. The bones indicate an animal as large as the red-throated Diver. Some bones are like the living genus *Colymbus*; others show resemblances to Grebes and Cormorants; and possibly, in the hip girdle, to penguins. The skull is singularly like that of the red-throated Diver in size and form, and the joints of the backbone are similar, but not identical. The femur, the thigh-bone, was more than 1½ inch long; and the drumstick bone of the leg develops a process like

a patella at the knee-joint, but it is much smaller than in the Grebes. The bone may have been 4 inches long. The metatarsus differs from the bone in all existing birds, because it shows no sign of the tarsal bones being blended with it. It was probably about 2½ inches long, so that the animal may not have exceeded a height of 15 inches. It is unknown whether these birds possessed wings. The saddle-shaped mode of union between the vertebræ of the neck is as well developed as in existing birds; but it is either absent in the back, or imperfectly developed, since joints of the back-bone have the ends cup-shaped. There is no evidence that the tail was short. It is certain that this bird was a water-bird, and it probably fed under the water, like the divers. It is named *Enaliornis*. In the Greensand of New Jersey birds have also been found which show strong affinities with the living divers; and since those birds possess teeth, it is not improbable that teeth were also present in the jaws of the bird from the Cambridge Greensand. The bi-concave condition of the dorsal vertebræ of Enaliornis is also found in one of the American genera.

The existence of these fossils goes to show that the family of divers already existed in the cretaceous seas; and that their jaws were armed with teeth, which are not found in any birds of more recent date. Birds have also been found in the Chalk of Seania in Sweden but the bones are few.

CHAPTER XIX.

CHALK.

THE superposition of the chalk upon the Upper Greensand, and the rocks which represent it, was the consequence of a rapid depression of old continental land from which the sediments had been denuded which built up the lower cretaceous beds. Land did not entirely disappear at once. There are a few places in Europe in which the cretaceous flora is met with, such as Aix-la-Chapelle, Halden in Westphalia, Quedlinburg and Blankenburg in the Harz, Molletin in Moravia, and Niederschœna in Saxony. The fossil plant-life found in these localities differs a little, but includes similar types to those in the cretaceous rocks of Greenland, and North America. At Aix, the cretaceous basin consists of sands and sandstones about 300 feet thick, which rest upon the old primary rock which had been a land surface. The sands have been regarded as of the age of the Upper Chalk, though they contain some shells of the age of the Upper Greensand.

The chalk abounds in scattered fragments of ancient crystalline rocks in its lower part. In some localities in the south-east of England its lower beds contain enough clay to give it an aluminous odour; while, in the west of England, its lower beds frequently contain grains of quartz. Proximity to land is indicated almost as definitely by the preservation of branches of *Sequoia*, in the lower chalk of Cambridgeshire, and all through the chalk period large timber trees are found

which have sunk water-logged, more or less destroyed by the borings of the ship worm *Teredo*. The presence of the remains of animals, like the flying Ornithosaurs and the long-bodied lizard *Dolichosaurus*, also indicate proximity to land. The larger part of the chalk is supposed to have been accumulated in moderate depth of water, because the rock almost everywhere shows evidence of slow changes of currents on the sea-bed.

The chalk is divided into four deposits, partly on the evidence of its physical characters, and partly from the nature of its fossils. The lower part of the rock, often termed Chalk Marl, comprises the Grey Chalk of Dover, which is coloured with clayey matter, and is known as the Chalk Marl and Totternhoe Stone. The bottom beds contain many univalve shells, and many survivors of the remarkable series of Cephalopods, named *Scaphites* (boat-shaped), *Turrilites* (spirally turreted), *Baculites* (staff-like), etc., which are so characteristic of the Gault and Upper Greensand.

The *Lower Chalk*, which succeeds the Chalk Marl, terminates upward in the bed known as the zone of *Holaster sub-globosus*. It is thin in the eastern counties, but becomes thicker in the south of England. It is covered by the Melbourne rock, a bed formed of chalk boulders, embedded in a paste of chalk, and resting upon a plane of erosion as marked as that by which the Cambridge Greensand rests on the Gault, indicating a change of level, which uplifted the underlying deposit.

The overlying beds are the Middle Chalk. This part of the chalk lies between the Melbourne Rock below, and a hard phosphatic bed above, known as the Chalk Rock, which rings

under the hammer. Between these limits the Middle Chalk is about 350 feet thick in Buckinghamshire and Bedfordshire, and more than 200 feet thick in Cambridgeshire. It is thinner in the North Downs. It contains some thin beds of flint in the Upper part, which is known as the zone of *Holaster planus*. The Middle Chalk is a great lenticular deposit, which is frequently marly, as though a quantity of clay had been deposited, while the chalk was being built up, by the growth of its characteristic organisms. This portion of the chalk has been thought to derive its clay from the old land, of which the Cambridge Greensand is evidence in the previous period of time, the intermixed clay being the finer river mud carried out into the ocean from a region of ancient and crystalline rocks removed to a greater distance in the depression of land. On this horizon there are multitudes of cup-sponges with siliceous skeletons, of the genus *Ventriculites*. The Middle Chalk is chiefly conspicuous for wanting most of the peculiar Cephalopods of the Lower Chalk, and for wanting the sea-urchins and starfishes of the Upper Chalk.

The Upper Chalk, which is only about 250 feet thick in the North Downs near Croydon, attains its maximum thickness north and south. At Norwich it is about 500 feet thick; and in the Isle of Wight its thickness may be 1000 feet. At Lyme Regis its thickness appears to be reduced to 50 feet. It is whiter and softer than the chalk below. The flint which characterises it occurs sometimes in horizontal tabular layers, in the planes of bedding. Sometimes they are in concretionary nodules, fantastically irregular in form, which are not absolutely limited to the planes of

bedding; occasionally these concretions are connected together by tabular flint. The flint nodules have grown since the upheaval of the chalk, and they are, as a rule, scantily developed on the opposite side of a slight dislocation wherever the chalk has been strained and fractured, as along the valley of the Thames. The vertical layers of flint which have been deposited in such fissures have cut off the water supply; so that the flints are large on one side of such a barrier and small on the opposite side.

FIG. 32.—The shepherd's heart sea-urchin, Micraster cor-anguinum, from the Upper Chalk.

When the chalk is examined under the microscope about one-half of its bulk appears to consist of microscopic organisms, of the group foraminifera, some of which appeared in the oldest rocks and survive at the present day. The more important of these foraminifera comprise the heavy shell, shaped something like a nautilus, named *Cristellaria*, the broader shell more like an Ammonite, named *Planorbulina*, the spiral shell resembling a pond snail *Bulimina*, and the little *Globigerina* formed of spheres, which succeed each other in a depressed spire. The other half of the chalk consists of a multitude of fragments, largely formed of the prisms which compose shells of mollusca, flakes of the shells of *Terebratula* and *Rhynchonella*, and minute fragments of corals and Bryozoa; and when these organisms cannot be

recognised, the material is amorphous and a product of decomposition of organisms. This may be evidence that a large part of the substance of the chalk not only consists of the remains of animals which preserve their forms, but that the remainder of it passed through the bodies of animals which have left little other record of their existence.

FIG. 33.—The base of Galerites sub-rotundus, showing the central position of the mouth from the Upper Chalk.

The fishes are the chief link between the Chalk and the Upper Greensand; a large number of small sharks of the two deposits being identical. There is the greatest contrast between the beds in mineral character; and in the principal types of fossils, because the Upper Greensand gives a record of conditions of the shore where sediment was accumulating; and the chalk gives evidence of conditions in the open sea, almost beyond the limit to which sediment was carried, thus demonstrating how great the difference in fossils may be with a slight interval in time. The conditions compared are such, in the two deposits, as may be found on the one hand on the south-west shores of Ireland at the present day, and on the other hand on the ocean floor 400 or 500 miles to the west in the Atlantic, where an organic deposit is now accumulating which closely resembles the chalk. But the sharks on the Irish coast are not limited to the shore, and leave their remains in the open ocean as well; exactly as happened in the ages of the Upper Greensand and chalk. Just as sea-urchins occur

scattered through the chalk, so they are found living on the chalky floor of the Atlantic Ocean; and the modern representative is sometimes very closely allied to the ancient fossil.

The chalk is no exception to the law that the fossils change with every few feet of a deposit from its base to the top. Thus there are numerous genera of sea-eggs of the order termed Echinoidea, some living and others extinct found in the Lower Chalk such as *Salenia*, *Pseudodiadema* and *Holaster*. *Ananchytes*, *Galerites*, *Micraster* and *Cyphosoma* characterise the Upper Chalk. This succession of fossils in the several beds of chalk is traced through the country.

There is no evidence in the chalk itself, at least in England, of its deposition coming to an end. Its newest beds at Norwich give no sign of shallow water conditions. Its highest beds in Holland, however, are the yellow granular limestone of Maestricht, which indicates a nearer approach to a shore than the chalk of England. In Denmark univalve shells, which from time to time lived in the chalk sea on definite horizons, like the Totternhoe Stone and the Chalk Rock, are found in the newest chalk to include shells which are not known otherwise till the tertiary period, such as the genera *Cypræa Oliva* and *Mitra*. They indicate that the shore conditions of the chalk sea are returning in its newest beds in consequence of a general upheaval of the sea-bed into land in the European region.

CHAPTER XX.

LOWER TERTIARY.

THE tertiary rocks occupy the basins drained by many of the rivers of Europe. And although they sometimes occur far inland, and at considerable elevations above the sea, as in the Alps, Atlas, and many of the mountain chains of the old world, they are necessarily among the most recently elevated parts of the earth's surface. Occasionally there is a possibility that one deposit extends continuously from the upper cretaceous to the lower Tertiary. The evidence of this continuity in time is only found in North America, in the "Laramie formation," in which there are no marine fossils; but which in Texas, California and British North America abounds in plant remains, and yields some vertebrata which favour that conclusion. It would therefore appear that in some parts of the earth there is no break between the secondary and tertiary rocks in time, any more than between the other rocks which give records of geological time. The tertiary beds, when followed in their succession from the oldest to the most recent, show an increasing number of the species of fossils to be still living, while the number of genera which are extinct becomes successively smaller. The geographical distribution of the surviving life, however, is always different from that of the fossil life. There is a succession of tertiary floras; the older are Oriental and Malayan and Australian in their affinities; succeeded by others which have a greater analogy with the existing flora of the

western part of North America. There is a similar geographical relation of the fossil shells in the lower Tertiary rocks. They are at first essentially the shells of the south coast of Asia, but afterwards include many forms which can only be paralleled at the present day at our Antipodes, so that the life which is now found in many distant regions, passed in successive ages over the same area of the earth, and furnished fossils to the rocks which were laid down upon successive portions of the sea-bed as it slowly moved onward.

The oldest tertiary strata in Europe are those of Mons in Belgium, where the chalk is bent down into a trough, which received the waters of a shallow sea at an earlier period than the chalk of Great Britain, so that it carries an older deposit of tertiary age. In like manner the east of England was depressed at an earlier period than the country in the meridian of Reading, so that the beds in the eastern part of the Thames basin are the oldest in the British tertiary series. The Montian fossil shells of Belgium include many which are common to the deposits of the lower tertiary period.

Thanet Sands.

The Thanet Sands are the oldest tertiary bed in Great Britain. They are a wedge-shaped deposit of sand which occurs in the east of the trough known as the London basin. It is 90 feet thick at Canterbury and Herne Bay, and thins westward, being absent to the west of a line from Leatherhead to Hertford. It is a marine deposit, abounding in shells, most of which live on into the London clay. There is a *Pholadomya*, a

genus which survives in the West Indies, and the *Nautilus Sowerbii*, a species met with in the London clay, but most of the other fossils are of such genera as occur upon the British shores at

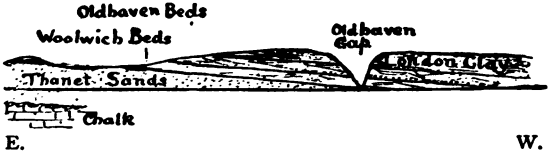


FIG. 34.—Cliff section of the Lower Tertiary Strata; east of Herne Bay in Kent.

the present day. The commonest are species of *Cyprina* which resemble the living *Cypriana Islandica.* The sands are nowhere consolidated; usually of a yellow colour, almost free from any mixture of pebbles, but sometimes yielding, in the east of Kent, a few rounded flints which show that the chalk had begun to be denuded, and contributed some particles to the crystalline grains of quartz which form the sand. Under the name Landenien inferieur, the Thanet Sands are traced into Belgium, being well seen about Brussels. They are also traced into France by way of Calais, but it is not certain that they extend into the Paris basin. The land surface which occurs at Gelinden, near Liège, makes known a large flora similar in some respects to that of Aix, with oaks like those of the mountain districts of Asia, with laurels, willow, ivy, and other familiar types of vegetation.

Above these beds succeed the Woolwich and Reading beds 25 feet in east Kent and 90 feet under London. They are the upper Landenien of Belgium and the north of France, sometimes

known as the zone of *Ostrea bellovacina*, and *Pectunculus terebratularis*. Ascending the Thames these beds are at first marine sands, differing but little from the Thanet Sands. At Upnor, near Rochester, they become estuarine, and consist of layers of rounded pebbles and alternations of clay, sands and shell beds. This condition continues up the Thames valley, and the marine shells, which were scarcely distinguishable from the shells of the Thanet Sands at Herne Bay, give place to fresh-water shells under London. At Loampit Hill remains of terrestrial plants and insects also occur. At Reading there is a flora of matted leaves, referred to species of fig and laurel and allies of the evergreen oak, in the lower part of the sands. These deposits, which were formed in fresh water, alternate with beds containing marine shells which have a long range in time, some occurring in the Montian beds and surviving to the London clay. It is therefore shown by these Woolwich and Reading beds and their fossils that the dome of the Wealden district, between the Thames and the English Channel, was raised into land; and that the chalk which once covered it furnished the flints which were rolled into completely rounded pebbles before they were

FIG. 35.—Ostrea bellovacina, from the Thanet Sands. The shell has grown on a branch of a tree.

swept down into these tertiary beds, which are now exposed on the northern slope of the North Downs.

With the oscillations in level a part of this land area at least supported the vegetation which furnished those beds of lignite which extend by Woolwich and Bromley, and the forest trees, which show by their leaves a marked resemblance to those of Gelinden. This indicates that the ancient connection, by continuous land, between the south-east of what is now England and Belgium and Hanover, was maintained in the tertiary period just as it had been in the older epoch of the Weald.

In one locality, near Rheims in France, the lower tertiary beds have yielded many remains of mammals which foreshadow lemurs and rodents. Among these occurs the *Neoplagiaulax* which seems like a survival of the *Plagiaulax* of the Purbeck beds. This is worth recalling on account of the resemblance of the tertiary plants of this horizon with the cretaceous flora. The *London clay* indicates depression which banished the shores of the tertiary land to some distance. There are oscillations in its level which varied both the mineral character of the stratum and the fossil life.

FIG. 36.—Cyprina Morrisi in Thanet Sand.

At the base there is usually a bed of small rounded flint pebbles known as the basement bed, with sharks' teeth. The clay gives evi-

dence at its base of terrestrial life, and near proximity to land, in the presence of a few mammals, some of which are allied to the existing tapirs. With these are found crocodiles of the type now living, and fresh-water tortoises, such as frequent estuaries at the present day.

The middle of the clay abounds in crabs and lobsters. While the top bed, about 50 feet thick, is rich in plants represented by the fruits of a large flora. The upper beds, like the basement beds, are sandy. At Bognor the sand at the base is calcareous and concretionary, with many marine fossil shells.

The London clay is 500 feet thick in Essex and Sheppey. It thins to the west and south-west; being 400 feet under London, 300 at Southampton, 200 at Alum Bay and 100 at Studland Bay on the opposite coast. To the south-east it is thickened with the sands in its lower part. Its fossil shells, such as *Cyprea*, *Murex*, *Conus*, *Pleurotoma*, *Fusus*, are of types which abound in the seas to the south of Asia. The plants which occur in its uppermost part also have an Asiatic character. The conifers are well represented by Cypresses, the *Sequoia*, Pines, and the Yew *Salisburia*. The lilies include the so-called American aloe, *Agave*. A species of *Smilax* represents the Sarsaparilla tribe. Bananas are known from the genus *Musa*. The ginger order is represented by *Amomum* which yields Cardamoms. *Nipa*, a screw pine common on the banks of the Ganges and in the Malay peninsula, is by far the most abundant fruit. It is associated with many palms, among which the areca palm, the nutmeg type, the fan palm of the south of Europe *Chamerops*, and the great palm *Sabal* are conspicuous. The oak, hazel, walnut, liquid amber, laurel,

magnolia, ebony and spurge are present, as are representatives of some medicinal plants like *Strychnos*, which yields nux vomica, and of *Cinchona*, which yields quinine. There are representatives of the tomato and melon. Apples are represented by *Cotoneaster*, and associated with almonds and plums. The cocoa is represented by a species of *Theobroma*. There are several limes and maples. Water-lilies are represented by the Lotus, and the Victoria lily of tropical America.

The London clay is well developed in Belgium and in the north of France. It does not reach the Paris basin in a recognisable form; though it may be represented by the lignites and sands of the Soissonnais. But neither the lignites in France, nor the Ypresien beds which represent the London clay in Belgium, yield the abundance of fruits which is met with in the Isle of Sheppey. Some of the Belgian specimens of Nipa are much better preserved than the macerated and compressed fruits of Sheppey, as though they were deposited without being so long in the water.

Above the London clay are the sands which cap the hills at Harrow, Hampstead, Highgate, High Beech, Haveringate and many places in Essex, having formerly been spread continuously all over the London clay, as they still are between Egham and Aldershot. They form Ascot Heath and Bagshot Heath, and are known as the Bagshot Sands.

The lower part, termed Lower Bagshot Sands, thickens in the Isle of Wight to about 800 feet, and forms the brilliantly coloured vertical sands of Alum Bay. They are laminated with films of clay at Woking, where the thickness is about

100 feet. Beds of pipeclay frequently occur; and occasionally, as at Newbury, the pipeclay contains fossil leaves like those at Bournemouth.

In the Isle of Wight the bands of pipeclay are exceptionally pure, as though they had been derived from white felspar, but never extend far. They are usually only a few inches thick, though occasionally thick beds are found. From them a flora has been obtained, which, although known only from the leaves of plants, indicates many of the types at the top of the London clay which are

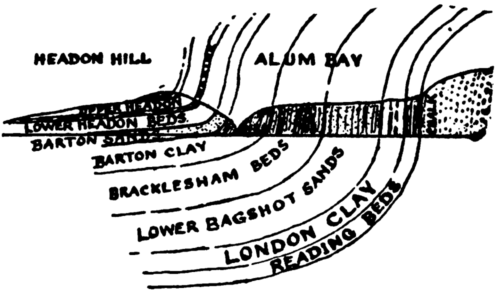


FIG. 37.—Cliff-section, Alum Bay, Isle of Wight, showing the relation between the vertical eocene beds of Alum Bay and the more horizontal oligocene strata of Headon Hill.

known only from fruits; so that they may well be regarded as a surviving part of the vegetation of the London clay. Among these Alum Bay plants are some of the Cypresses and *Sequoia*, *Smilax* and the palm *Sabal* is identified in both. There is the same arum named *Aronium*. The oak, walnut, laurel, cinchona, ebony, magnolia, maple, the soapworts Sapindlus and Cupania, the allspice and Eucalyptus, the almond and plum, and the

mimosas are common to both deposits. Besides these, the Alum Bay beds make known many new types, of which the London clay gives no evidence. Among them are the beech, elm, fig, bread fruit, willow, poplar, sandalwood, the Mezereon, Aristolochia, olive, ash, convolvulus, verbena, bilberry, some heaths, the aralia, dogwood, white water-lily, custard apple, holly, buckthorn, vine, sumach and pistachio. These are among the more important new plants introduced in the Bagshot Sands; and with them are a number of Proteaceæ, referred to genera now living in Australia, as well as a representative of the type genus *Proteoides*, the sugar bush of South Africa. One of the most striking features in the flora is the small number of palms, and the absence of the Nipa, which in Sheppey is the predominant fruit and is present in the newer beds at Bournemouth. The fruits and leaves, like the shells in the associated strata, indicate affinities with the life of far-off regions of the earth. It is a generation since Unger, a Viennese student of the fossil plant-life of the lower tertiaries, impressed with the occurrence of numerous genera in Austria, which live at the present day in Australia, regarded the eocene flora as indicating a migratory passage of the ancient plants from Europe into the Australian region. The plane of junction where the Bagshot Sands come to an end, and the succeeding marine *Bracklesham beds* begin is not easy to draw; because the Bracklesham beds contain locally thick layers of lignite, which have the aspect of a coal seam, and indicate the persistence of terrestrial conditions and some oscillations of that terrestrial surface in level.

Low down in these beds is found the large

foraminiferous shell named *Nummulites lævigatus.* It does not form a thick bed; but probably marks the geological horizon of the Nummulitic Limestone, which is one of the most important limestones in the old world, and extends from the Alps and Carpathians into Thibet, and from Morocco, Algeria and Egypt through Cabul and the Himalayas to China.

In Great Britain the Bracklesham beds in Sussex and the Isle of Wight are alternations of green sands and sandy clays, which are separated from the overlying Barton clay by a conglomerate formed of rounded flint pebbles. At Bournemouth their character has changed. They are foxy-brown estuarine sands with beds of pipeclay, in which occurs another flora, with many ferns, palms, cactus, eucalyptus, figs, willows, beech, and nipa. The cactus is an American type. Subsequently the North American type of vegetation became more abundant in Europe in the middle Tertiary period, and better defined by many genera. The *Barton clay* succeeds the Bracklesham beds. It is a blue clay, about 300 feet thick, with an extraordinary number of fossil shells, many of which are similar in genera to those found in the London clay and Bracklesham beds, though the clay is characterised by the abundance of individuals of the genera *Chama*, *Crassatella*, *Fusus*, and *Voluta*, and by the presence of some peculiar genera like *Typhis*, a univalve similar to Murex, except that the spines are tubular. There is no such fauna anywhere to be met with at the present day. It is not unlike a blending of the existing Malayan and New Zealand forms of marine life; and many of the shells, like the *Crassatella*, *Typhis*, *Chama*, *Pecten*, *Pectunculus*, are very similar to

species now living in or about the New Zealand seas.

The Bracklesham beds have generally been regarded as represented by the Calcaire grossier of the Paris basin, while the Barton clay corresponds to the grits with the *Nummulites variolarius*, and some newer deposits, such as the Gres de Beauchamp. These beds are well represented in Belgium. The Bracklesham beds have yielded some interesting serpents of the genus *Palæophis* though not so large as those of the London clay. In the Barton clay occurs a marine mammal, of the genus *Zeuglodon* shown by its back bone to be a true whale, which has the teeth double-rooted and serrated in a way that is seen in no other animal, though resembling some seals.

The Barton period comes to an end with a deposition of 200 feet of sand, in which fossils are rare.

Theoretically, the Bracklesham and Barton beds together are an immense expansion of the middle 50 feet of the Bagshot sands at Aldershot, which contain, in some of the clayey layers, impressions of fossils which appear to be identical with those found at Barton in Hampshire, and Bracklesham in Sussex. On this hypothesis the Bracklesham and Barton beds indicate in the Hampshire area a depression of the old sea-bed, into which peculiar faunas successively moved. The upper Bagshot or Barton sands bring back again the conditions of a shoal, or shore, due to a general uprising of the land. The few shells which have been found in them are Barton species.

The sea-bed continued to be elevated until it passed into a land surface, in the succeeding

period of time termed *Oligocene*, which is the only part of the middle Tertiary represented in Great Britain.

CHAPTER XXI.

MIDDLE TERTIARY.

The Middle Tertiary period, usually termed Miocene, makes a more striking approximation in its life to the animals and plants which exist at the present day. In the European area it is a record of terrestrial and lacustrine conditions, alternating with the deposits of shallow seas.

In Great Britain only a portion of the earlier part of the Miocene period is represented by deposits which now cover the northern part of the Isle of Wight, much of the New Forest, and are exposed in the cliffs at Hordwell, Tollands Bay, at Bembridge and Hempstead. These strata are grouped together as Oligocene.

Headon Beds.

The oldest oligocene beds, known as the Headon series, are 130 feet thick at Headon Hill, in the Isle of Wight, are in the main fresh-water strata. They comprise first, about 70 feet of brackish water marls, and fresh-water limestones, superimposed upon the marine sands above the Barton series. This proves that the shallow sea, with the Upper Bagshot Sands for its floor, had become converted into dry land, upon which lakes were formed by fresh waters draining into the bottom of the trough from a limestone region such as the chalk or the oolites.

The strata and their fossils show that the level of the land fluctuated. The lakes became sometimes occupied with brackish water, so that marine life divides up the fresh-water deposits. After the lower fresh-water beds were formed, the land was submerged, so as to give rise to the Middle Headon beds, which are essentially marine. There are great banks of oysters with numerous marine shells, most of them similar to the types which had previously been known in the Barton clay. These marine beds became better developed at Brockenhurst in the New Forest, where some corals are found, together with the vertebral column of Zeuglodon, a marine mammal of the whale type, with teeth like seals, already known from the Barton clay. These marine beds are widely spread in Germany. After they were deposited the land was raised once more, and the Upper Headon beds formed, which reach a considerable thickness. They are fresh-water deposits, consisting of marls frequently green, full of the large *Paludina lenta*, the *Cyrena obovata* and the extinct *Potomomya plana*, which alternate with thick limestones, commonly full of fresh-water shells of the genera *Planorbis* and *Limnæa.* These limestones are almost entirely the product of the growth and decay of the fresh-water plant *Chara* which precipitates carbonate of lime upon its tissues by absorbing carbonic acid gas from the water charged with carbonate of lime. In these limestones remains are found of terrestrial mammals of the types present in the Gypseous beds at Paris, although they are not so numerous as in the Bembridge beds.

When the Headon beds are followed to the coast of Hampshire, the limestones disappear,

leading to the conclusion that the upheaval of the chalk, which now runs in a nearly vertical position through the Isle of Wight, had already begun to supply the calcareous matter, which the streams brought into the lakes of the Headon period.

The beds which rest upon the Upper Headon strata are termed the *Osborne or St. Helen's series.* They are sandstones and marls, much thicker than any of the sandstones and marls in the Headon beds, and therefore in contrast to them. Some of the sandstones become calcareous, and pass into concretionary limestones. The shells are all of fresh-water types. The sandstones are sometimes ripple-marked, probably by the wind.


FIG. 38.—Planorbis euomphalus and other fossils in the fresh-water Headon limestone.

The Osborne beds are about 80 feet thick, and divide the Headon from the Bembridge beds. The *Bembridge Limestone* is thick, very like the Headon limestones, rather creamy in colour, full of the same types of fresh-water shells, and containing many land shells, especially examples of the genera *Helix*, *Bulimus*, and *Glandina*. These land-shells have a marked affinity with species now living in North America, with which one or two may be identical. The Bembridge limestone abounds in seed-vessels of the plant Chara, which formed it. Remains occur in it of several species of the extinct mam-

mal *Palæotherium* which in some ways approximated in structure to existing tapirs.

Where this limestone caps Headon Hill it is about 15 feet thick. The Bembridge marls rest upon it successively in the section at Hempstead. They are grouped into a number of sandy beds and shaly clays, full of estuarine shells, among which are the genera *Melania* and *Melanopsis*, which alternate with beds containing *Cyrena* and other bands in which the shells are of fresh water species.

The top of the marls is the remarkable thin deposit known as the Black Band which is usually grouped with the overlying Hempstead series.

The Hempstead Beds.

Hempstead Hill lies to the east of Yarmouth in the Isle of Wight, on the shore of the Solent. It is formed of about 170 feet of fresh-water and estuarine marls, capped by a marine stratum. The marls have a general resemblance to the Bembridge marls. The Black Band at the base is about two feet of clay, coloured with vegetable remains, among which *Sequoia* and water-lilies have been recognised, together with the teeth of *Palæotherium* and other mammals and remains of tortoises and crocodiles. It is an old terrestrial surface on which rest, first, the lower marls with *Melania muricata;* secondly, the middle marls with *Cerithium Sedgwicki;* and thirdly, the upper marls with *Cerithium plicatum.* At the top are the Corbula beds which contain several marine shells in addition to the estuarine forms, among them *Voluta Rathiera*, Natica, Corbula, and a species of oyster. The characteristic mammal of these

beds is the *Hyopotamus*. These are the newest British deposits in the Isle of Wight of oligocene age.

The lignites alternating with clays which fill up the basin at Bovey Tracey in Devonshire are probably of the same age. They form deposits about 300 feet thick; probably once thicker. With the exception of a single beetle, the remains found in them are about fifty species of plants. The lignite itself is chiefly the flattened trunks of the *Sequoia Couttsiæ*. About half the plants are regarded as of peculiar species and the remaining twenty-five occur in the Miocene of Germany and Switzerland. Among these trees are species of fig, oak, laurel, cinnamon, the sour gum tree Nyssa, a palm, vine, and some ferns such as Lastrea.

On the Continent the Miocene beds attain singular importance. Not only from the part they take in forming the basins drained by so many rivers, and in the structure of the Alps, but also on account of the remarkable mammalian remains which they yield.

The *Dinotherium*, which appears to have been a sort of Mastodon with tusks in its lower jaw, is one of these. The three-toed horse, named Hipparion, is even more interesting, while the fossils obtained at Pikermi, near Athens, include giraffes and many other animals which have long passed away from Europe. Perhaps the most extraordinary Miocene fauna is found fossil in the Siwalik Hills in India, which lie between the Jumna and the Ganges, and rise to a height of 2000 or 3000 feet. The species of Hippopotamus, and allies of the giraffe and other African types which are there found, testify that change of

area in the distribution of genera on land in the Tertiary period, continued as persistently as the migrations of marine life in the Primary period.

CHAPTER XXII.

THE CRAG.

After the great terrestrial epoch of the newer Miocene period had passed away entirely unrepresented by strata, in Great Britain, deposits, named the Crag, are found, which fringe the coast in Norfolk, Suffolk, and Essex, occur in a few places in Kent; and in Belgium.

The relative age of these beds was first determined by the method of counting the number of existing species in each of the tertiary strata. On that basis the tertiary epoch had been divided into Eocene, or lower Tertiary, Miocene, or middle Tertiary, and Pliocene, or upper Tertiary. Subsequently the Lower Miocene was named Oligocene. In the Pliocene the fossils include more than 35 per cent. of living species.

In this great period the Crag finds a place. The older beds, named Coralline Crag, have 84 per cent. of the shells still living; and in the newer or Red Crag 92 per cent. of the shells still exist.

The Coralline Crag rests unconformably upon the London clay. Its lower part consists of yellow false bedded sands, which sometimes form a building stone about 30 feet thick. This sand appears to have been derived from denudation of the Bagshot sands which once extended over the

whole area of the London clay. The shelly beds include a number of kinds of life which are now only represented in southern seas. As many as two hundred species are said to be found living in the Mediterranean, and a few are paralleled off the coasts of Japan, Mexico and the West Indies. But while about sixty-five of the species are known only in southern seas, fourteen only in northern seas, and seventeen have been met with in no other deposit, there are as many as 185 Coralline Crag shells still found in the British seas.

The rock is named Coralline Crag from the large extent to which its upper beds consist of the remains of Polyzoa which were formerly termed corallines. Of those Polyzoa which are still living, 26 out of 30 are met with in British seas, but the majority of the fossils belong to the two extinct types *Alveolaria semiovata*, and *Fasicularia aurantium* with which are some species of the genera *Retepora Idmonea* and *Eschara*. The fishes of this crag include the common cod, green cod, power cod, the pollack, whiting, and whiting pout, with which have been found the great teeth of the shark *Carcharodon*, and of *Otodus*.

FIG. 39.—Cardita senilis, from the Coralline Crag.

At the base of the Coralline Crag, in places where the shark's teeth are found, is a bed of nodules of phosphate of lime, in which bones of the dolphin *Choneziphius* occur with teeth of the whale *Balænodon*, associated with teeth of

deer, rhinoceros and *Mastodon* which were obviously derived from a land surface, and perhaps from an older deposit. In this bed are multitudes of fossils from the London clay, and a few crocodiles and Plesiosaurs derived from the older Secondary rocks.

The characteristic shells of the Coralline Crag, besides the comparatively rare species of *Voluta*, *Cassidaria*, *Pyrula* and *Lingula*, include many species of the genus *Astarte*. That genus which now characterises northern regions, is here represented by multitudes of individuals. The *Cypriana islandica*, *Terebratula grandis*, *Cardita senilis*, *Buccinum dalei* are typical fossils.

The Red Crag.

After the Coralline Crag was formed in some tranquil depth of water, the shores appear to have been upheaved. And on the eroded surface about 20 feet of false bedded sands and comminuted shells were laid down, as shore deposits, which fringe the island-like masses of white or coralline crag. This newer deposit, named *Red Crag*, indicates three or four successive depositions. Each of its beds was planed level by denudations, which left thin layers of pebbles and nodules of phosphate of lime at the junctions.

It has been observed that the older Red Crag at Walton on the Naze, has fossils more like the species of the Coralline Crag than are found elsewhere. At Butley a zone abounds in northern species, and on this is a newer crag still. The Red Crag along the river Deben contains a larger number of terrestrial mammals than has been found at the base of the Coralline Crag. The

additional types comprise species of tapir, the Siwalik *Hyænarctos*, hyæna, *Hipparion*, besides deer, bear, and among marine animals a *Halithe-*

FIG. 40.—Fusus antiquus reversed variety, from the Red Crag.

rium and a walrus with large tusks. The shells are interesting from the dominance of a few types, such as the reversed variety of the *Fusus antiquus*, which is associated with the common whelk, the European cowrie, the common purple shells, and species of the genera *Nassa*, *Emarginula*, *Pectunculus*, *Mya*, *Lucina* and *Cardium*. At Norwich the Red Crag becomes estuarine. The Forest Bed of the Norfolk coast may be a part of its land surface. A patch of Crag is found north of Penzance, at St. Erth, 98 feet above the sea. A more interesting deposit on the summit of the Chalk descends into pipes in the Chalk at Lenham in Kent, indicating that denudation has removed the Crag from the surface of the country.

All through the crag the temperature on the east coast was becoming colder. This is evinced by the presence of stones in the newer crag which appear to have been floated southward in ice; and it may be indicated by the increasing number of shells which at the present day characterise

northern and arctic seas. Eventually the crag land was covered with boulder clay, and the whole country experienced glacial conditions. The cold is attributed by some to change of form in the earth's orbit, by which the winters increased in length. Others attribute it to upheaval of land. Upheaval of Scandinavia and the North Sea would displace the shells southward, and lead to a condensation of vapour, from which glaciers would result large enough to cross the plain of the North Sea and reach Britain.

CHAPTER XXIII.

GLACIAL PERIOD AND GRAVELS.

So manifest a break in the succession occurs with the superposition of the Glacial deposits upon the Crag, that some geologists regard them as beginning a fourth great division of the strata which is named Quaternary or Post-tertiary. Others place them in a division of the Tertiary period, which is named Pleistocene. The singular feature of the formation which justifies a separate name is the wide spread of the glacial conditions over the Earth. In many countries where ice now is only a passing incident of Winter, clays are found, blue, purple, or brown, full of fragments of rocks which are mostly local, though many have travelled from distant places. These boulders, which cause the deposit to be named Boulder Clay, are often smoothed and grooved or scratched on one side

like stones which have travelled in the sides or bed of a Glacier. The deposit is often indistinguishable from the clay found in Alpine valleys, from which Glaciers have retired which once covered the country. The high ground in every land in which Boulder Clay is found supports this inference with evidences of the work of ice. The Mountains of Scotland, the Lake district of England, and the Snowdon district in Wales are smoothed and grooved by sheets of ice which have passed away. Small joints in the old slates have been widened and deepened in the valleys, until rounded structures have been produced like the backs of huddled sheep at rest. This condition known as *Roches moutonnées* is sometimes exposed by a retreating glacier in the Alps, and is manifestly due to the work of frost and glacier ice.

Above many a mountain valley, such as the Pass of Llanberis, angular stones are perched in positions where water could never have left them. They are regarded as having been the stones of moraines once carried on the surface of a glacier, and left behind in their present places when the ice melted beneath them. The great blocks of crystalline rock above Neuchatel are of the same substance as the Mont Blanc chain, and could only have reached their present position upon the limestone chain of the Jura by crossing the central valley of Switzerland. On such evidence Glacial conditions for a country may be inferred even though boulder clay is not seen.

In North America Sir J. W. Dawson has described the evidences of the Canadian ice-age as comprising, (i.) a Lower Boulder Clay, which

rests upon a glaciated and grooved surface of rock; (ii.) The Lower and Upper Leda-clay with marine shells and drift plants; and (iii.) an Upper Boulder Clay with the shell *Saxicava*, and gravel. The Lower Boulder Clay forms the basins of the great Canadian lakes. The boulders are mostly of Laurentian gneiss. Their striation is attributed to the grating of pebbles included in shore-ice upon the rocky floor beneath, when moved by the tide.

In Britain the glacial deposits are spread irregularly. They consist of Upper and Lower Boulder Clays on the east coast, divided by Middle Glacial Sands with marine shells.

The granite of Criffel in Kirkcudbrightshire is found in the boulder clay over Lancashire and North Wales. Boulders of Volcanic rocks from Cumberland are scattered over Cheshire. Distinct streams of glacial drift extended down both the east and west sides of Britain. The boulders of Westmoreland Shap granite found over the plain of York and between Whitby and Scarborough on the coast, prove that boulders were also distributed eastward from local centres, notwithstanding the Scandinavian source of many rocks in the Boulder Clay on the Norfolk Coast at Cromer. The Boulder Clay found near London at Finchley, and at Hornchurch in Essex, is full of travelled ice-grooved rocks, with fossils from the secondary strata of Yorkshire and Lincolnshire. Glacier ice transported the rock matter, but probably shore-ice and icebergs were partly concerned in depositing it, so as to fill up the old valleys and leave the clay on the surface of the country. The denudation since the glacial period has been very great, and the glacial beds

are cut through by modern valleys which are excavated in the underlying deposits.

In many parts of the east of England a series of gravel beds occurs beneath the Boulder Clay, and in these pre-glacial gravels, chipped flint implements of the Palæolithic type are said to be found.

In the east of England the Boulder Clay which caps hills is itself capped by coarse hill gravel which has the aspect of being boulder clay from which the clay has been washed out. The gravels descend to lower and lower levels till they occupy the broad shallow troughs through which existing rivers flow, from which we may infer that elevation of the land has gradually contracted the width of existing rivers. Chipped flint implements are found in both the high and low level gravels, with remains of mammals, which are mostly African in their affinities, and mostly extinct. They include species of *Hippopotamus*, *Rhinoceros*, *Elephas*, Lion, Bear. Deer, Horse, and Ox survive in Britain.

Evidences of severer frosts are found in the broken rock fragments, and of periodic floods due to melting of the snows. The leaves of the dwarf birch and dwarf willow are preserved in clay seams, with the land and river shells which now exist.

As hunter or as husbandman the rude forefathers of the British people left in rock shelters and caves simple works of art which show that people had gained a primitive civilization who lived when the post-glacial gravels were formed, and the influence of glacial conditions was still felt.

The dominance of man over animal and plant

may mark the beginning of a new geological period; but there is no gap in time or change in life to announce the human period, or to distinguish it in kind from earlier epochs in the story of the Earth.

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